Pedestrian acceptance of delivery robots

Appearance, interaction and intelligence design

Master thesis
Stef de Groot

TU Delft

Deutsche Post DHL Group

Graduation report by Stef de Groot
August 2019
Faculty of Industrial Design Engineering at Delft University of Technology

For further information and contact:

Deutsche Post DHL Group
Contact: Uwe Radetzki
Title: Vice President of Innovation
Email: uwe.radetzki@deutschepost.de

Stef de Groot
Master: Integrated Product Design
stef@stefdegroot.com
www.stefdegroot.com

Technical University of Delft
Project chair: Dr. Rusák, Z.
Title: Assistant Professor Industrial Design Engineering
Email: z.rusak@tudelft.nl

Project mentor: Prof. dr. ir. Geraedts, J.M.P.
Title: Professor of New Mechatronic Design

Acknowledgements
This project wouldn't have reached the level of quality without the people that helped me along the way. I want to thank Zoltan Rusak for his enthusiasm and critical view, especially when it comes to the testing and simulations; Jo Geraedts for his critical view and his reminders of designing for the bigger picture; Uwe Radetzki and Mr. Beckman from Deutsche Post DHL Group for their feedback from the business perspective and giving me the necessary understanding of logistics practice.

Virtual reality was integrated into the project for testing, visualizing and simulating. I couldn't have done this without the help of everyone at the VR-Zone. They helped me out with all the problems that I encountered and spend much time on translating my design into Unreal Engine 4. I want to thank Arno Freeke, Luuk Goossen and Arend-Jan Krooneman for all their help and efforts and not getting tired of my questions. They taught me a lot about this upcoming technology. I also want to thank Roland van Roijen for helping me with producing the video and the beautiful shots of the robot in context. His camera-work, color grading skills and feedback on the storyboard significantly improved the quality of the final result.

I also want to thank everyone participating in my interviews and user experience tests. With their help and philosophical insights into pedestrian-robot interactions, I retrieved the biggest insights of the project. I also want to thank Doris Aschenbrenner with her help with the setup of the first user test.

Thanks to Paul for his critical feedback on the report, making it more enjoyable and understandable to read.

I want to thank everyone that supported me along the way. All friends, family and other students that made doing this project feel less like a solo effort, even during the summer holidays.

Project structure

What factors influence delivery robot acceptance?
Analysis is done to find factors that play a key role in influencing the acceptance of delivery robots. This is done by literature research and interviews about opinions towards robots, robot aesthetics and robot interaction.

How will delivery robots be perceived in the future?
Looking further than the products that already exist, opens up the possibility for innovative ideas. By using the Vision in Product Design (ViP) method, a vision is shaped for how we will interact with delivery robots in the future.

Design goal
A design goal was compiled based on all previous research and ViP method.

Ideation
Ideation was done on formgiving, ways in which the robot communicates its intentions and how pedestrians can have control during the interactions. The most promising solutions were selected.

User experience virtual reality (VR) testing
The chosen design variations were visualized in an interactive environment. With user tests in VR, the best indicator that the robot could use was selected and how interactions should and shouldn't happen.

Robot behavior simulation
To define design parameters of how the robot should operate in complex environments, simulations were made in Unreal Engine 4. The 3D-visualization allows for evaluation of the robot's behavior, by taking part in the simulation yourself.

Redesign
A redesign was made, based on all insights from the user tests and the simulations. A final form, interaction, and recommendations for further research and development are proposed.

Executive summary

Technology developments are making it possible to start automating the last-mile of parcel logistics. This raises the question of how these autonomous technologies will interact with humans. The goal of this project is to design a concept of a delivery robot for DHL, that maximizes acceptance by pedestrians.

Literature research and interviews showed that the appearance of the robot should be highly functional efficient to communicate what the function of the robot is and how it will behave. Cues that improve the understandability of the behavior should be emphasized in the design. Creating aesthetic associations between other logistics products and the robot makes it more familiar.

The level of in which the robot is perceived as a social emotional being should in be in line with peoples' expectations and needs. How much anthropomorphization is applied on the robot, determines if the robot is seen as a machine, cute or creepy and forms expectations on how to use it.

The goal is to create a product which fulfills its function without disrupting regular pedestrian behavior and without eliciting negative reactions or sabotage from pedestrians. In order to achieve this, the interaction should be very low effort and intuitive. Pedestrians are not the customer and do not want to adapt their behavior dramatically to cope with tens of delivery robots on their sidewalk stroll. Intuitive interactions can be achieved by using the same way of interacting as with known entities, like other pedestrians or vehicles. Tests show that a design in which the behavior of the robot is modeled after standardized pedestrian behavior, could result in favorable interactions. In demanding situations, the robot will use a car-like blinking light, to communicate what its intentions are.

In user experience tests in virtual reality, small body cues from the robot were seen as an important communication tool on top of a predictable maneuvering. In the final design, the four wheels are made highly visible by a higher body and lights under the chassis. Suspension control allows the body of the robot to lean into corners and forward just before braking, to visually accentuate and communicate the impending action.

The sum of all the small cues and the path of the robot are intuitively understood by pedestrians and don't need much attention while interacting. Pedestrians will feel in control, because the robot behaves predictable and it mingles in with the natural flow of pedestrians.

The behavior of pedestrians and robot are simulated based on the "social-forces model". The outcome of the simulation is a first definition of desirable robot behavior and what parameters are needed to achieve this. It is found that the robot should have a less dynamic way of moving than pedestrians. It should steer slower and move with less speed changes. It should be very early in communicating its directions by already turning into that direction a few meters before encountering a pedestrian.

Although the social forces model is now used within simulations, it can also be implemented as the basic logic of DHL's future delivery robot. However, more tests are required with live test subjects, to find definitive conclusions.

Table of contents

Project structure 4

Executive summary 5

Table of contents 7

Introduction 8

Research phase

Pedestrian acceptance 11
- Defining acceptance 11
- Acceptance models 12
- Opinions in social media 18
- Pedestrian interviews - opinions on acceptance 20
- Acceptance discussion 22
- Acceptance conclusion 22

Appearance 24
- Pedestrian interviews - opinions on appearance 24
- Product semantics 28
- Acceptance discussion 34
- Acceptance conclusion 34

Pedestrian-robot interaction 35
- Social forces 35
- Pedestrian interviews - opinions on interaction 37

Future vision 38
- Past products 38
- Past interaction 39
- Past context 39
- Future context 40
- Future interaction 41
- Future product 41

Design goal 42

Design phase

Intent indicators 46

Control during interaction 48

Form considerations 50

Design direction 1 52
Design direction 2 53
Design direction 3 54
Design direction choice 55

Evaluating the intent indicators 56
Evaluating gesture communication 58
Reconsidering pedestrian-robot interactions 59

Robot behavior simulations 61

Evaluating social forces behavior 66

Form detailing 68

Evaluating the redesign and robot cues 74

Feasibility 76
- Technical feasibility 76
- Cost price 76
- Viability 79

Discussion 80

Conclusion 81
- Overal conclusion 81
- Design goal 81
- dRAM 82

References 84

Appendix
- A. Design brief 87
- B. dRAM motivation 91
- C. Workshop PostBot team 93
- D. Pedestrian interviews 97
- E. Indicator and gesture user test 112
- F. Robot behavior simulation 125
- G. Social forces and cues user test 151

Introduction

Last-mile challenge
Due to the increase in e-commerce shopping activities, parcel logistics is expanding. One of the biggest challenges of current practice, is delivering in the last-mile, the last few kilometers before the final destination. A package delivery employee has to bring every package to a different address, park its car and hope that the customer is home. This makes the last-mile one of the most expensive parts of the process.

Last-mile automation
This project is based on the vision that using autonomous technologies in the last-mile can be the basis for new delivery solutions. Autonomous technologies can operate without human supervision by sensing the environment and acting based on that. Adding this technology to logistics processes could improve the efficiency of the overall system and make parcel delivery more affordable. Furthermore, delivery robots can provide new services that fit better with the need of the customers, like faster deliveries and a more reliable service.

Defining a robot
A robot is a machine which is designed to perform complex tasks automatically (Rouse, sd). They are capable of autonomous decision making and adapting to situations, based on data from sensors and other devices (Pagallo, 2013).

The delivery robot is a type of service robot, which is an adaptable interface that interacts, communicates and delivers services to an organization's customers (Wirtz, et al., 2018). Within this category it falls under the professional service robots with functions in logistics.

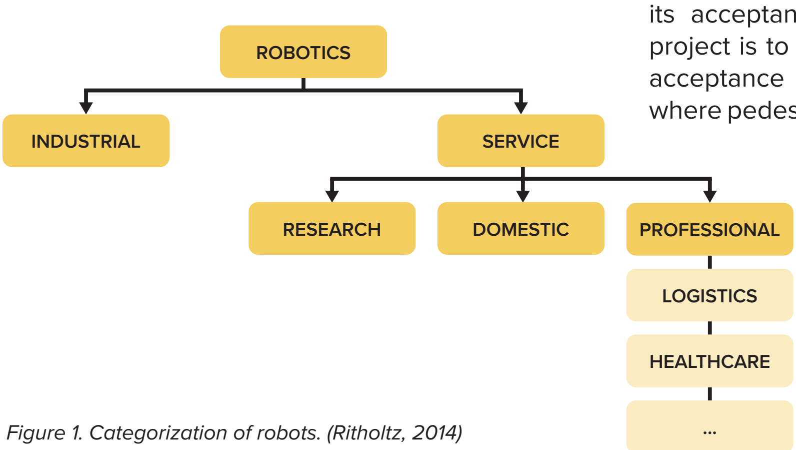


Figure 1. Categorization of robots. (Ritholtz, 2014)

The delivery robot could be a social-robot, which is specifically made to have social-emotional intelligence. It is made to have a deeper connection with the user and is therefore often used in healthcare, to keep elderly company or to help children with autism practice on social skills (Darling, 2015). Based on the tasks that the delivery robot is performing, it doesn't have to be a social-robot. However, pedestrians might need or expect some social-emotional behavior.

The starting point
For this project, the starting point is a delivery robot which drives over the sidewalk. It is loaded with packages by a large truck or at a local distribution location. The robot then starts its journey over the sidewalk to deliver all packages. The customer can choose for specific delivery time-frames, is more flexible in changing delivery locations and is always up-to-date about the exact delivery time. When finished, the robot is picked up by a large truck for reloading new parcels and potentially repositioning the robot to another neighborhood.

The challenge of acceptance
New product adoption in the urban environments is not always with the consent of citizens. During the implementation of the delivery robot into urban environments, citizens will have a large effect on its success. A negative attitude or behavior towards the delivery robot could be detrimental to the functioning of the device. For instance, if people deliberately counteract against the device. On the other hand, the efficiency of the device and the brand perception of DHL can improve when there is a positive attitude towards the device and the service it is delivering.

The assignment
The robot's appearance and the way it behaves on the sidewalk will be of crucial importance to its acceptance by pedestrians. The goal of the project is to research how these aspects influence acceptance and to design a concept of a robot where pedestrian acceptance is maximized. It is also looked at what machine intelligence is needed to create desired robot behavior.

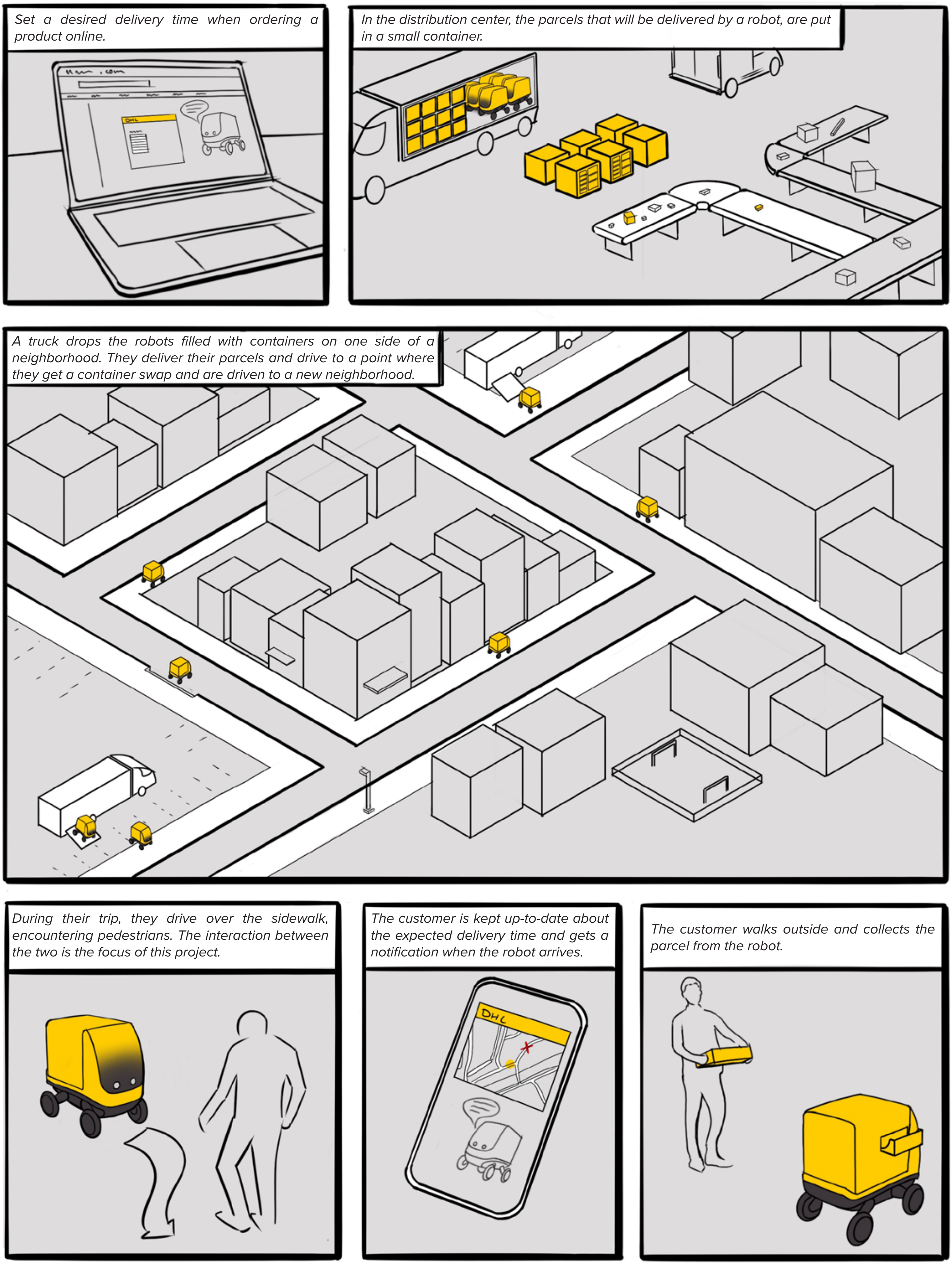


Figure 2. A potential application of the sidewalk robot in the logistics system.

Research phase

A deeper understanding of the factors influencing acceptance of robots in the public domain is gained through literature research and interviews. These are hereafter called acceptance factors. Furthermore, people's opinions on delivery robot appearance are analyzed to set up requirements. Research into pedestrian behavior on sidewalks is done, to form a context in which the robot will act. The last main part of this phase is the development of a future vision, by using the ViP method.

The research phase concludes with a design goal and a plan of action for the design phase.

Pedestrian acceptance

To maximize the level of acceptance of the delivery robot, we need to understand what acceptance entails and what factors have an influence on it. This chapter focuses on developing an understanding of acceptance factors, by reviewing literature, setting up an acceptance model, review opinions in social media and from the pedestrian interviews.

Defining acceptance

Acceptance of innovation is defined as the positive decision to use it. Therefore, it is the opposite of innovation refusal (Taherdoost, 2017). In the context of a delivery robot, the decision of pedestrians to use it is less voluntarily. Therefore, acceptance can also be described as the willingness to coexist with the delivery robot on the sidewalk. Ideally, acceptance is high enough that pedestrians are also willing to cooperate with the robot, if the robot needs help. On the other side of the spectrum, there can be annoyance towards the delivery robot. The robot is still able to perform its task, but might experience some counteracting by individuals. In the worst-case scenario, there is a full rejection from society. At this stage, it is not possible for the robot to operate and there might be significant damage to the brand image of DHL. A realistic scenario will be a combination of different reactions by pedestrians. The goal is that the design of the robot influences that the average level of acceptance is on the right side.

Figure 3. Possible acceptance outcomes

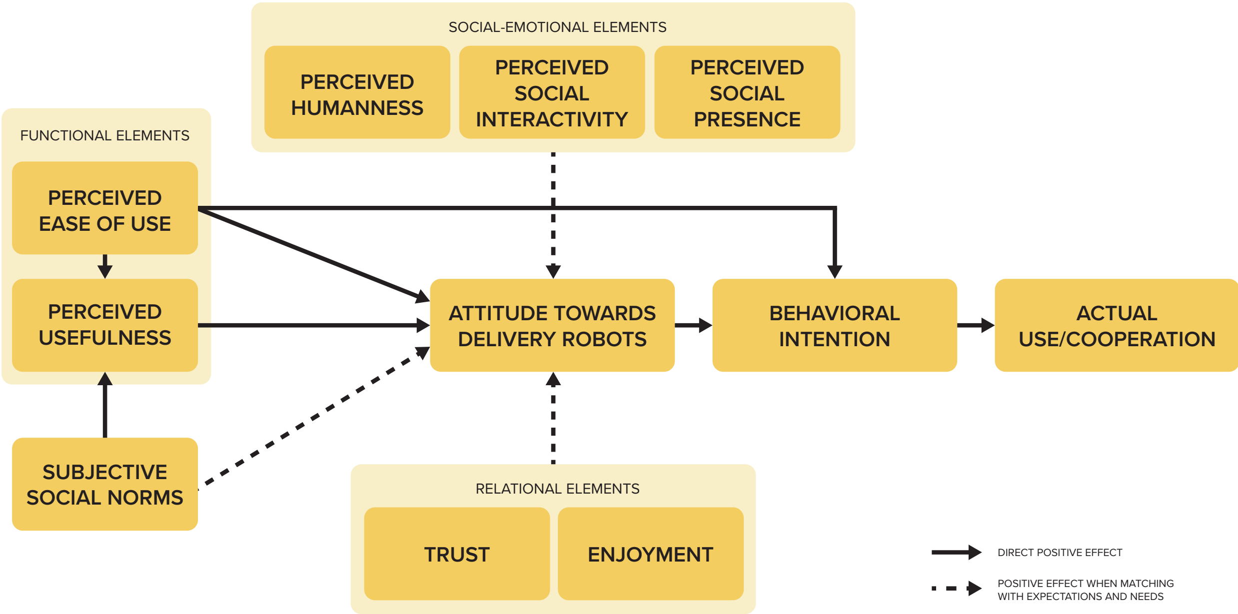


Figure 4. The Delivery Robot Acceptance Model (dRAM)

Acceptance models

To predict the acceptance of the delivery robot, it is useful to start with a model proposed in literature that can predict this. The "Technology Acceptance Model" (TAM) describes that acceptance of information technologies is determined by the "perceived usefulness" and the "perceived ease of use" (Davis, 1989). However, to sufficiently cover the complexity of a robotic system that can potentially show some social-emotional elements, it needs a more comprehensive model. An extension on TAM which provides this is the "Service Robot Acceptance Model" (sRAM) (Wirtz, et al., 2018). TAM and sRAM form the basis for a project specific model: "Delivery Robot Acceptance Model" (dRAM). dRAM can be seen in figure 4. See appendix B for a motivation about the choices made during the development of this model.

In the model can be seen that the functional elements "perceived ease of use" and "perceived usefulness" are having a direct positive or negative influence on the attitude towards the robot. A match between the robot and the experienced subjective social norms will have a positive effect. The social-emotional and relational elements are depending on the preferences that pedestrians have. Depending on the type of robot and the context, a person might not have the need for social interactivity or a human-like design. More social-emotional and relational elements are therefore not always better. Acceptance comes with a match between the robots features and the needs of the user.

The main elements of the dRAM model are explained below and how they might influence acceptance.

Perceived ease of use
According to Wirtz et al. robots have the potential to be easier to use than some other technologies (Wirtz, et al., 2018). The authors explain that robots often have an unstructured interface and guides the user though the process. If users make mistakes, the robot can correct them. In their opinion, this is different than self-service technologies, like ticket machines, that have a fixed interface and won't help users when they make mistakes. Wirtz et al. predict that robots will in general not face much problems on functionality. However, this can be different with a delivery robot. Pedestrians could value their ease of walking on the sidewalk highly. The robot might reduce this ease of walking by blocking their path or by giving them mental discomfort.

Acceptance of robots is influenced by the belief of control in previous experiences (Broadbent, Stafford, & MacDonald, 2009). Positive previous experiences improve the user's self-efficacy (Bartneck, Suzuki, Kanda, & Nomura, 2009). Graaf, Allouch and Van Dijk (2019) showed that if people expected to have the necessary skills to use a social robot, they had higher intentions of using them. They also found that people that thought of being personally innovative, which is the willingness to experiment with or try innovative technologies, have a more positive expectation about the ease of use.

To improve the ease of use of a delivery robot, the interaction with people on the sidewalk is very important. It should be researched what way of interacting fits with the mental models of people. An example of an easy to use robot characteristic would be a predictable maneuvering. The robot will be easier to use if it moves out of your way and if you can predict in which direction it will go.

Perceived usefulness

Usefulness is strongly linked with the behavioral intention (Ezer, Fisk, & Rogers, 2009). It is also the most important acceptance factor for robots that fulfill a social-emotional task (Davis, 1989).

Pedestrians are confronted with the device, while they might not be a customer of DHL. The perceived usefulness they experience as pedestrian will therefore be different from what they experience as customer. Customers might also have had negative experience with the service and therefore think negatively about the device as pedestrian.

There are also other motives for a positive or negative perceived usefulness. There could be a perception of an impact on society. Pedestrians could think that the device affects the amount of jobs available or that it endangers their own job. Another societal affect could be that more robots on the streets could endanger the amount and quality of human-to-human communications.

There are opportunities to increase the perception of usefulness for pedestrians by providing them services at the moment they encounter the robot. This can be postal services, like the possibility to send a parcel, providing information about the area or emergency support.

Subjective social norms

The total of all perceived social pressures to engage or not engage in a behavior are called subjective social norms (Amherst, sd). Especially in the scenario in which a technology is accepted for the first time, this social context is important (Rogers, 2003). The author states that if other important role-players, like friends or role-figures in social media, support the use of the technology, an individual will grow one's status in that group by also using that technology.

Perceived humanness

Perceived humanness is the level in which humans conceive the robot as a human being (Wirtz, et al., 2018). The attribution of human features onto objects by the observer is called anthropomorphism. A delivery robot can be anthropomorphised by pedestrians based on its behavior and its aesthetics.

Even though that people believe that a device doesn't possesses human-like emotions, they apply social characteristics to them (Nass, Steuer, Henriksen, & Dryer, 1994). Even with very machine-like robots like a Roomba vacuum cleaner, people assign names and genders to their device (Sung, Grinter, & Christensen, 2009). Robots tend to be anthropomorphised based on three characteristics: their movement, physical embodiment and their mimicking of human behavior, like sound, movement and social cues (Darling, 2015).

Higher levels of anthropomorphism in a robot can have benefits, but also downfalls. A robot can be less threatening while it is performing a functional task and therefore more accepted by people (Darling, 2015). Some social robots are mainly popular because of their anthropomorphised characteristics. This effect can also be achieved by anthropomorphic framing, like giving it a name and describing its social aspects on introduction (Darling, 2015). Darling (2015) has suggested that this framing results into a higher level of empathy towards the device and makes it less likely that people perform a violent act on it.

Emotional attachment however towards the robot, could negatively influence the intended use of the robot (Darling, 2015). A good example is a bomb deployment robot from the United States military. The colonel stopped a testing exercise, because he couldn't bear the inhumane sight of the robot putting itself in so much danger (Darling, 2015). Darling suggests that for robots that are not performing a social function or are enhanced with social interaction, it is better to prevent deliberately designed anthropomorphic characteristics. This is to prevent any negative effects on the robots functioning.

The delivery robot is not performing a social function, but could have some ways in which the social interaction enhances the performance. For instance, the way it maneuvers around people or the way it communicates intent. On the one hand, it can be hypothesized that some deliberately designed anthropomorphic characteristics could increase the level of empathy that people feel, which increases the chance of people helping the robot when it needs help, or to accept it in general on the sidewalk. A pitfall is that a high level of anthropomorphism gives the impression that the robot wants to have interactions with people, which hinders its efficiency in delivering parcels. Another scenario could be that it feels disappointing if people expect the robot to be able to have a verbal interaction, but the robot is not able to talk. In general, it should be noted that people anthropomorphize robots very quickly. This can already be provoked by the movement of the robot on itself and the fact that it has a physical embodiment, especially when the movement has similarities with human movement. It might not be needed to mimic human non-verbal communication to reach a desired level of humanness.

The Uncanny Valley theory, as can be seen in figure 5, visualizes the relation between how human-like a robot looks and how familiar people think they are (Mori, MacDorman, & Minato, 2005). Very machine-like robots have a low level of familiarity, which increases once robots get human characteristics. At a certain point, which is called the Uncanny valley, the robot looks quite real, but is perceived as odd and scary. Once the robot looks almost similar to a human, familiarity goes up again, to its highest point.

Woods (2006) studied the preference of children between the age of 9 and 11 on their opinion about robots (Woods, 2006). This age group considered robots with a combination of mechanical and human features to be friendlier than only mechanical robots. The author found that they see human-like robots as the most aggressive looking. Young adults imagine robots to be more human-like than older adults, when asked to imagine a robot for in their home (Ezer, 2008). In general adults feel more responsible when they cooperate with a robot which is machine-like, especially if the robot is in a subordinate position (Hinds, Roberts, & Jones, 2004).

Since the robot's main function is not to have social interactions with people, but to deliver packages, it is not needed to look like a human. This would be an extremely expensive endeavor and not efficient. The optimal human likeness is somewhere on the left side of the graph. Having a more machine-like design could be beneficial since it gives adults the feeling of higher levels of responsibility and it could prevent misconceptions about the intelligence of the robot. During the design of the delivery robot, humanness can be added in the movement, appearance, sound, verbal communication and non-verbal communication. Since people anthropomorphize rather quickly, human characteristics should be handled cautiously in the design process.

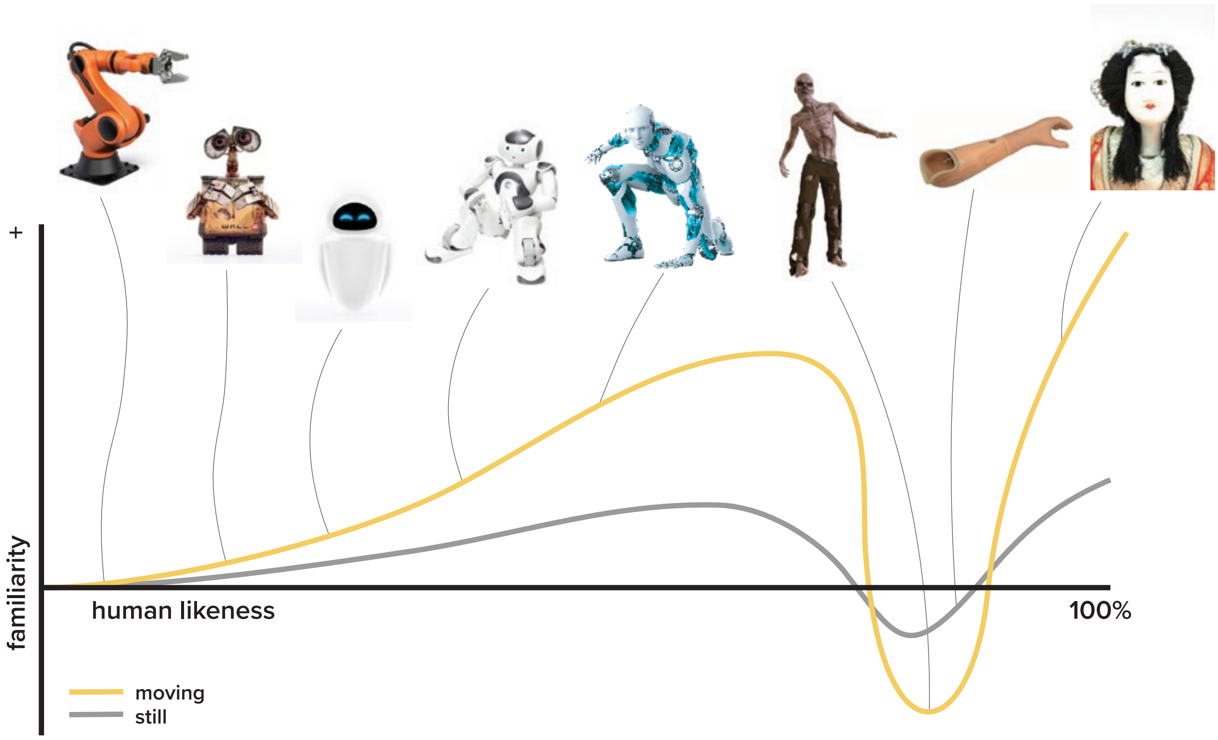


Figure 5. The Uncanny Valley with examples.

Perceived social interactivity

Perceived social interactivity is the level in which a robot expresses social intelligence. The robot should be observing social norms and act on them with appropriate actions and emotions (Wirtz, et al., 2018). This can be done by verbal and non-verbal communication (nodding, shaking head, shifting weight, eye movement, blinking, eye-tracking or expressing emotions). Breazeal (2003) suggests that to maximize robot acceptance it is important to design a social interactivity which matches with the social models that humans expect.

The Dutch population is not really appreciating the idea of social behaviors of robots in the home environment (Graaf, Allouch, & Dijk, 2019). In the same study the authors found that people think that a social robot with less companionship could adapt better to their needs. Another study also suggests that people largely expect utilitarian functionalities from robots and they are less likely to see them as socially interactive devices (Ezer, Fisk, & Rogers, 2009). However, Graaf et al. (2016) found that people actually behave socially with robots in their home, if they are using them (Graaf, Allouch, & Dijk, 2016). They talk to them and give them names. It seems to defer from person to person what the expectations and acceptance of social interactivity are. Some people appreciate social behavior and look forward to a time in which robots are more social (Graaf, Allouch, & Dijk, 2016). But the same authors found that other people experience unease when a robot unexpectedly starts a conversation.

The level of autonomy is expected to influence the perceived social intelligence of the robot (Beer J., Prakash, Mitzner, & Rogers). This influences the way people interact with the robot. Pedestrians could see the robot as highly autonomous and therefore expect that the robot is able to have a conversation with them. Or they perceive a lower level of autonomy and expect the robot only to be able to interact non-verbally, or not communicate at all.

In the case that the robot uses some lines of speech, to for instance, ask pedestrians if he can move through, it might create a mismatch between what social intelligence people expect and what the robot is capable of (Torrey, et al., 2006). They might expect the delivery robot to be able to have a conversation, based on it wishing them a good day. This mismatch between expectation and reality can affect acceptance.

Also, smaller, more unconscious interactions are influencing the understanding of the robot and could avoid miscommunication (Breazeal C. , 2002). An example is how jerky or flexible the robot is moving, which could influence perception of care. Another example is the believability of how the robot shows attention or reactivity in a conversation. In general, it is preferred that non-verbal communication has high resemblance with human behavior, compared to robot-like behavior (Rosenthal von der Putten, Kramer, & Herrmann, 2018).

Perceived social presence
Perceived social presence is the extend in which people think they are with another social being (Wirtz, et al., 2018). Wirtz, et al. describe it as having the feeling that the robot takes care and is really present in the moment. Mimicking of emotional responses can be a way to create a more pleasant experience for humans (Tielman, Neerincx, Meyer, & Looije, 2014). However, it is important that the users' expectations are in line with the actual social intelligence of the robot, (Beer J. M., Prakash, Mitzner, & Rogors, 2011). For instance, if the delivery robot would say hello to the people it encounters, they might think that the robot is able to have a conversation. If however, the robot is not able to have a social interactive conversation, people might get frustrated and disappointed.

In the interaction with humans, a robot can mimic the expression of emotions (Wirtz, et al., 2018)
There are surface-acted emotions and deep-acted emotions. Current robots are capable of surface-acted emotions. They are noted by humans, but users know they are not real. Especially at longer and deeper interactions, these emotions can be perceived as not genuine (Wirtz, et al., 2018). Humans are capable of expressing surface and deep emotions. Employees which deliver a professional service to customers and especially for jobs like doctor or psychologist, a deep social-emotional connection is needed. With simpler service roles, employees need mostly surface-acted emotions. Robots could be able to perform comparable or better, due to a higher consistency in their performance. (Wirtz, et al., 2018).

Facial expressions are an important way to show emotional state in interactions (Collier, 1985). It makes the conversation partner assume that the social agent cares about its surroundings (Bates, 1994) and makes the interaction more enjoyable (Bartneck, 2003).

A delivery robot doesn't need to be able to have full conversations to perform it's function. For that reason, no facial expressions are needed. However, facial expressions or other ways to mimic expressions of emotions, can give pedestrians the feeling that the robot cares about you and your safety and that it is intelligently looking at the environment.

Trust
Trust is the perceived goodwill and competence of the robot. On an emotional level, trust refers to the feeling of being secure and comfortable while depending on the robot (Wirtz, et al., 2018). Robots with more human-like characteristics are more likely to inspire trust (Tinwell, Grimshaw, & Williams, 2011). This works up to a certain level, as described above with the Uncanny Valley.

Graaf, Allouch and Van Dijk (2019) found that if people think they are personally innovative towards (robot) technology, they are more likely to feel safe around a social robot.

Enjoyment
The perception of joy can come from the perception of care and friendliness, the robot's ability to stimulate curiosity, or the experience of meeting personal goals with help of the robot. Graaf, Allouch and Van Dijk (2019) found that enjoyment was the largest factor to predict the intention of people to use a social robot in their home. Since the delivery robot is not necessarily a social robot, lower levels of joy could be appreciated more.

Time dependency of acceptance factors
Graaf, Allouch and Dijk (2016) describe that it is important to keep in mind that the acceptance factors a person values will change over time based on experience. The authors describe acceptance factors for social robots, which can form a hypothesis for a delivery robot. In figure 6, an overview can be seen on acceptance factors that people value before and during use.

Initially, when a person lacks experience with the specific robot, they base their opinions on functional elements. They look at previous experiences with similar products and their perceived self-efficacy, but also to a potential change in their personal status. Another factor that is important in this phase are trust factors like privacy concerns. Furthermore, users that are less confident about using the technology are more likely to be influenced by the opinions of others.

When the pedestrian starts interacting with the robot, the focus shifts towards the attitude that is coming from functional elements, based on actual experiences. In this stage, there is also a focus on the feelings while using the robot. During the first use stages, it is important that the interactions are enjoyable and that the perceived social presence is matching with the expectations. After longer periods of use, the social interactivity matching with the expectations becomes important.

During implementation of robots in society it is therefore important to first provide the right information to improve people's self-efficacy and make them more familiar with the technology (Graaf, Allouch, & Dijk, 2016). After adoption, it is important that people keep perceiving the robot as useful and with the right levels of enjoyability, social presence and social interactivity. The robot could keep on improving its social presence and interactivity after implementation of the robot in society, so it matches more with the needs of users.

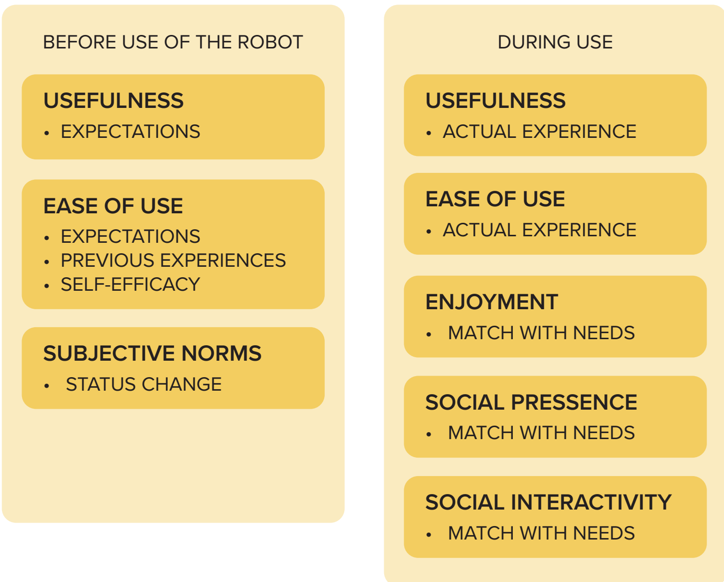
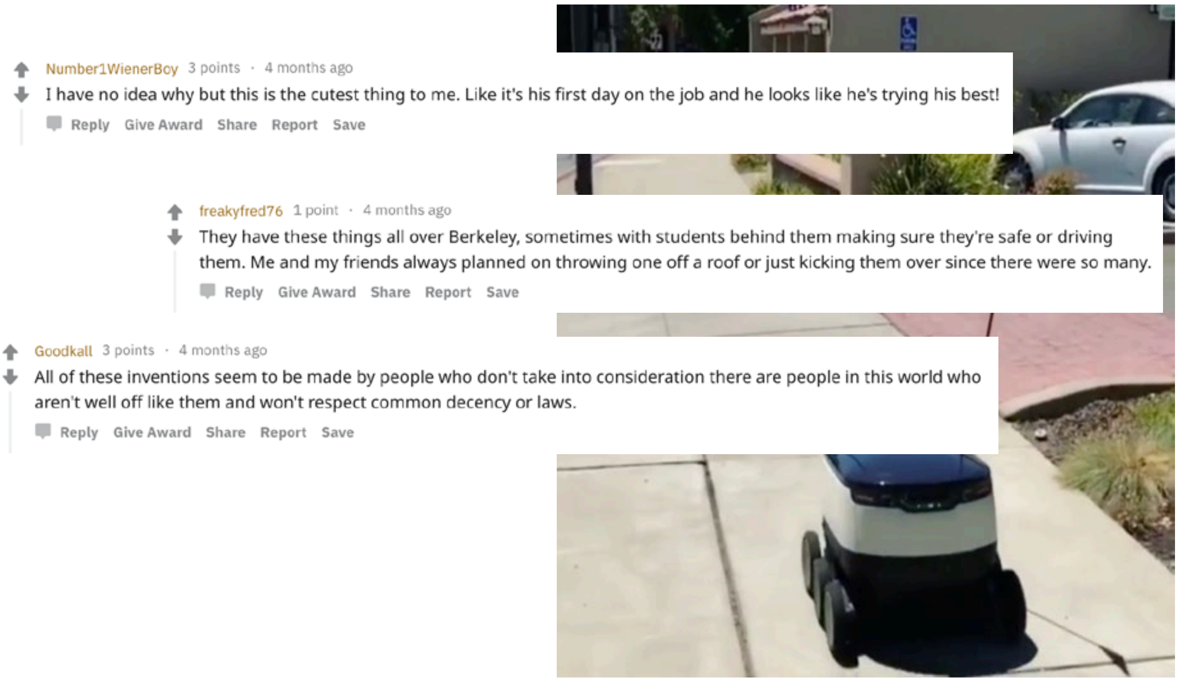
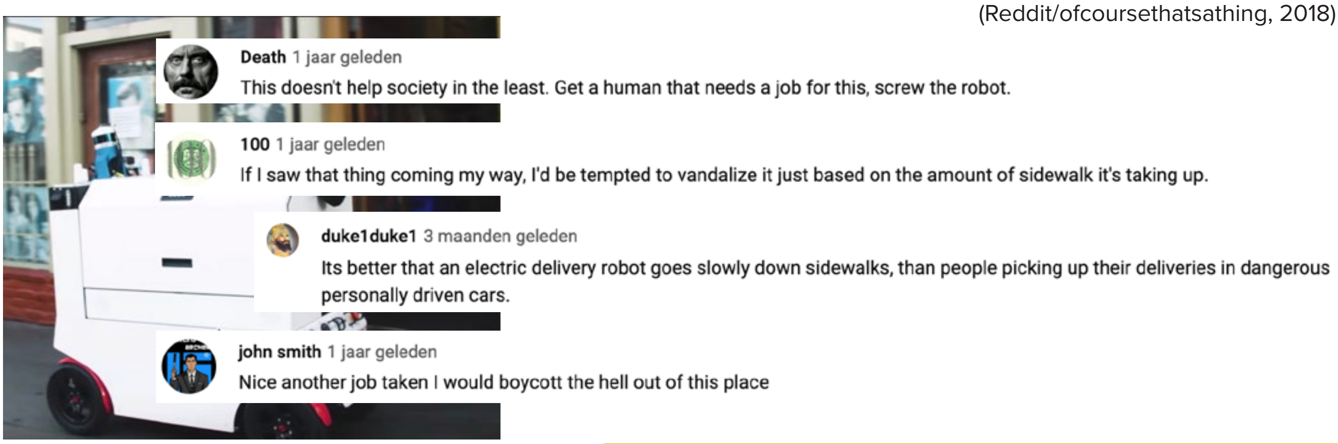


*Figure 6. Important acceptance factors in different stages of use, for social robots. (*Graaf, Allouch and Dijk, 2016)



(Reddit/ofcoursethatsathing, 2018)



(Youtube, 2017)

Opinions in social media

On social media like Twitter, Reddit and YouTube, it is easy to find extreme opinions about delivery robots. People feel free to say what they think and they are not afraid to talk in extreme wordings. In figure 7, an overview of some opinions on the internet can be found. It should be noted that there will be a difference in opinion between cultures. Furthermore, this overview gives no information about the amount of people that have the same opinion.

In general, a lot of people think that the robots would be vandalized. Especially when driving though rough neighborhoods, there would be people that would do something to the robot for fun or to steal contents or components. Some people say they feel the urge to vandalize the robot, like tipping it over or throwing it in the river, because the robot takes up space on the pavement, which annoys them.

Figure 7. Attitudes towards delivery robots on a variety of social media sources.

Posted by u/mvea 8 months ago

19.9k

People kicking these food delivery robots is an early insight into how cruel humans could be to robots

businessinsider.com/people...

Robotics

(Reddit/technology, 2018)

2.2k Comments · Give Award · Share · Save

AdrianBrony 62 points · 8 months ago · *edited 8 months ago*

I think a major thing left out of the discussion is frustration over the economics and general experience surrounding said property.

For instance, the scootershare company in San Francisco has massive vandalism problems because people feel the scooters are violating certain laws meant to protect pedestrians as well as generally act annoying.

Or the time a company tried using a robot to hassle vagrants in an area to go away and they found the thing destroyed and shoved in a nearby fountain.

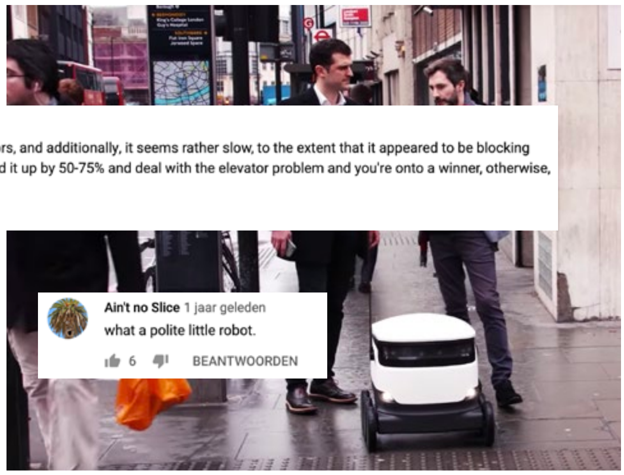
So they have a habit of ending up in the water not just because of random dickery but as a response to an unwanted intrusion in community life. It's sabotage rather than vandalism.

Give Award · Share · Report · Save

klyemar 1.5k points · 8 months ago

They really gloss over the fact that this company is planning on putting thousands and thousands of little mobile, trackable cameras everywhere. I wonder how long it would be before law enforcement would try to get their hands on that valuable data.

Give Award · Share · Report · Save



Decus 1 jaar geleden (bewerkt)

Good, but it needs the ability to use elevators, and additionally, it seems rather slow, to the extent that it appeared to be blocking people's access along the pavement. Speed it up by 50-75% and deal with the elevator problem and you're onto a winner, otherwise, I'm not too sure...

1 · BEANTWOORDEN

(Youtube, 2018)

Many commenters, especially under American media posts, are concerned with the employment effects of the robots. They believe that robots will take low wage jobs and say that people that have a higher risk of losing their job, should boycott their employer.

Another negative opinion, which seems less prominent on social media are the privacy concerns. The robots are seen by some people as movable, traceable cameras, which will be all around the city. There is concern that governmental institutes, like law enforcement, will get access to the data.

However, there are also positive comments. Some people express that they think the robot is cute. This appears to be more with the Starship and KiwiBot robot and less with the Marble robot. One Twitter comment showed that after helping “the little guy” to continue on its task, he felt like a “robot Robin Hood”.

Posted by u/Nalowale 2 months ago

Postmates reveals its cute, automated delivery robot

mashable.com/articl...

(Reddit/postmates, 2019)

17 Comments · Give Award · Share · Save

paid2drive 1 point · 2 months ago

Postmates couriers should all boycott this company immediately.

Gla-aki 5 points · 2 months ago

Postmates reveals public punching bag

Pedestrian interviews - opinions on acceptance

For the full documentation of the pedestrian interviews, see appendix D.

From the pedestrian interviews conducted with 9 people, it can be concluded that the participants had no prior knowledge about delivery robots. None of the them had ever seen one and their expectations about what it could be were varied: similar to a Roomba, a humanoid robot or a self-driving van. A delivery robot on the sidewalk will be totally new for the participants. There are no specific expectations that should be met to make the device fit in with their past experiences.

Opinions about a delivery robot on the sidewalk
See figure 8. The speed and size of the robot seem to be one of the main concerns, with six participants raising these issues. Two participants expected a higher speed than pedestrians, but prefer the robot to slow down when approaching people. Three participants raised concerns that the robot could be annoying to have on the sidewalk, because of their size, they might touch you and as a pedestrian you might need to adjust your behavior. One participant felt that as a pedestrian or cyclist, you are more vulnerable than a car and would therefor prefer the robot to be on the street. Two participants opinion about a delivery robot on the sidewalk is depending on the behavior of the robot, it should give priority to pedestrians and it should be clear what the device is going to do.

Opinions about a delivery robot compared with delivery vans
See figure 9. Three participants (all students), raised the issue of losses of jobs. However, for one of them, this can also be a positive thing, because he expects that delivering parcels is not a much fun job to do. One adult and two seniors raised the issue of less social interaction when receiving the parcel. Some positive aspects that participants expect are improved safety, less cars on the road, higher environmental friendliness and new and better services. Most participants didn't seem completely positive or negative about delivery robot implementation, except for one senior participant who was strongly against the loss of social interaction. Positive attitudes were mainly centered around less delivery vehicles on the street. This positive feeling could be increased by giving people the feeling that the robot is doing an efficient job to deliver packages and to decrease the need for delivery vehicles. Negative attitudes were mainly about losses of jobs and lack of social interaction. A way to solve the issue of loss of jobs during the implementation of the robot is to educate the public that robots and people will work side by side for a long period of time. With the current grow in e-commerce, a delivery robot will not be a thread to jobs. The issue of less social interaction could be solved by giving people the opportunity to have social interaction with the robot, or with a teleoperator.

PARTICIPANT	OPINIONS
1, 2, 9	It depends on their speed and size if the sidewalk is the best position.
7	It depends on their size if the sidewalk is the best position.
3	It depends on their speed if the sidewalk is the best position.
1, 4	Robots should adapt their speeds when approaching people.
1, 3, 4	It could be annoying to have on the sidewalk.
1	Preferably on the road, because you are vulnerable as pedestrian and cyclist.
1	Sidewalk is fine, but you want to know what the device is going to do.
2	The participant would probably cut the device off.
3	It doesn't feel productive for a robot to go over the sidewalk.
6	The sidewalk is fine if it gives priority to people.

Figure 8. Opinions about a sidewalk delivery robot from the pedestrian interviews.

PARTICIPANT	OPINIONS
1, 2, 3	It will cause losses of jobs.
6, 8, 9	Delivery employees provide social interaction.
3	It will become easier to steel parcels.
2	Delivery employees don’t always do their best work.
5	The trust is higher that a package will arrive in time.
1, 4	Delivery employees don’t drive safely.
5	Less cars on the road is better.
4	Delivery vans are not environmentally friendly.
1	It could provide new services.

Figure 9. Opinions about a delivery robot compared with delivery vans from the pedestrian interviews.

Preferred emotions during encounters
In figure 10, the preferred emotion and the associated robot characteristics of the participants can be seen. The three main outcomes are: the need to feel safe, the preference to not feel anything at all from encountering a delivery robot and feeling joy.

The two participants that indicated the need to feel safe, described that the robot would need to be visibly aware of its surroundings. Furthermore, its behavior should be fluent, empathic and it should know when to give priority to pedestrians.

In order to not be disturbed by the robot and not feel anything, the robot should, according to the participants, be of a modest size and act subordinate or equal to people.

For one participant, joy was the most important. For instance, by using humor in interaction or marketing. For another participant joy was mentioned, but feeling nothing was more preferred.

PARTICIPANT	PREFERRED EMOTION	ROBOT CHARACTERISTIC
1	Feel understood	Predictable, not intimidating
2	Nothing	Not to large, coexisting, subordinate
3	Safe	Aware, visible sensors, empathic movement, know when to give priority
4	Safe	Fluent movement, eyes to give sense that it sees you
5	Nothing / joy	Be equal, same speed, not too large
6	Joy / humor	Same marketing as Coolblue
7	Surprise (expected instead of preferred)	Because of the tech development
8	Wonder (expected instead of preferred)	Only if the robot is recognizable
9	Irritation (expected instead of preferred)	The robot creates an impersonal society

Figure 10. Preferred emotions by the participants and the important robot characteristics.

Acceptance discussion

There is quite some literature about technology acceptance and robot acceptance. However, not much is explained about how to use this knowledge in the design process. This demonstrates the relevance of this project. Furthermore, the literature is mostly about a context that are different from the delivery robot. Other, much covered contexts are social robotics, service robots and domestic robots. To the best of my knowledge, there is no literature about acceptance of robots on sidewalks, where the people that encounter it are not customers. It is therefore important to keep an open mind for deviations from what is described in literature.

Another point of discussion is how well the interviews give insights in the larger population. The interviews were done with 9 people from different age groups. It can be expected that the 3 students from the TU Delft are more open to accept new technologies, based on their background. The total of participants is not enough to give insights in the general population. An open mind should be kept during further research for other opinions.

Acceptance conclusion

In general the level of acceptance of the interview participants seem positive. Some of them would be curious when encountering a robot. None of the participants would be scared. However, this is depending on the behavior, since some mentioned that they would be scared if the robot would come really close. There was one senior participant who was very negative about the delivery robots, because more robots make the world more unpersonal. But in general, participants saw advantages of the robot over delivery vans. These vans are seen as dangerous, since they drive fast. Some concerns that they raised, like the theft risk of parcels and the lack of human interaction can be solved by design.

Functional elements
The functional elements have more positive influence on the attitude of pedestrians, once they are implemented more. Therefore, the ease of use should be maximized by the design. The size of the robot will influence the perceived ease of use. Too small and it inflicts danger of falling over it, too large and it blocks the field of view. The perceived usefulness should also be maximized. This can be done by improving the perceived effect on society and by delivering better services than the current way of delivering.

Social-emotional elements
The social-emotional elements of the dRAM, need to match with the needs and preferences of the users, in order to positively influence the attitude towards the delivery robots. Based on the literature, it seems that people anthropomorphize very quickly and that humanness is achieved with only minor design elements. A human-like robot will give the perception of a very socially intelligent device. But for the function of the robot, it probably doesn't need a close collaboration based on verbal communication. Programming a high level of social intelligence is expensive and not always successful, even within companies like Google and Apple.

The perceived humanness will probably need to be in the lower scale, since people anthropomorphize very quickly and to create correct expectations about the robots' social interaction capabilities. In the chapter about robot appearance, the results from the interviews will give more insight in these social-emotional elements.

The social presence of the robot is much linked with the humanness and the social interactivity. Increasing social presence by for instance using non-verbal communications, can improve the quality of interactions and make the robot more trustworthy and enjoyable.

In this project it should be sought for types of interactions, in which non-verbal communication acts beneficial. Not necessarily during conversations, but for other interactions in which it can give comfort to pedestrians and make them feel safe.

Relational elements
Trust should be matched with the need of the user. Since the interviews showed that people want to feel safe and want the robot to be predictable, it can also be expected that they want to trust the robot to a large extend.

The desired level of enjoyment is not yet clear. For social robots, joy is very important to keep using the product. However, the robot is not necessarily a social robot. Joy was mentioned during the interviews, however, there is a bigger need for not feeling any emotion at all during encountering a delivery robot. The two could however go hand in hand. A fun appearance/marketing such as Coolblue has, which is working "obsessively" to make customers happy, can easily be ignored by people that are not interested.

Figure 11. A Coolblue van, with a smiley in front.

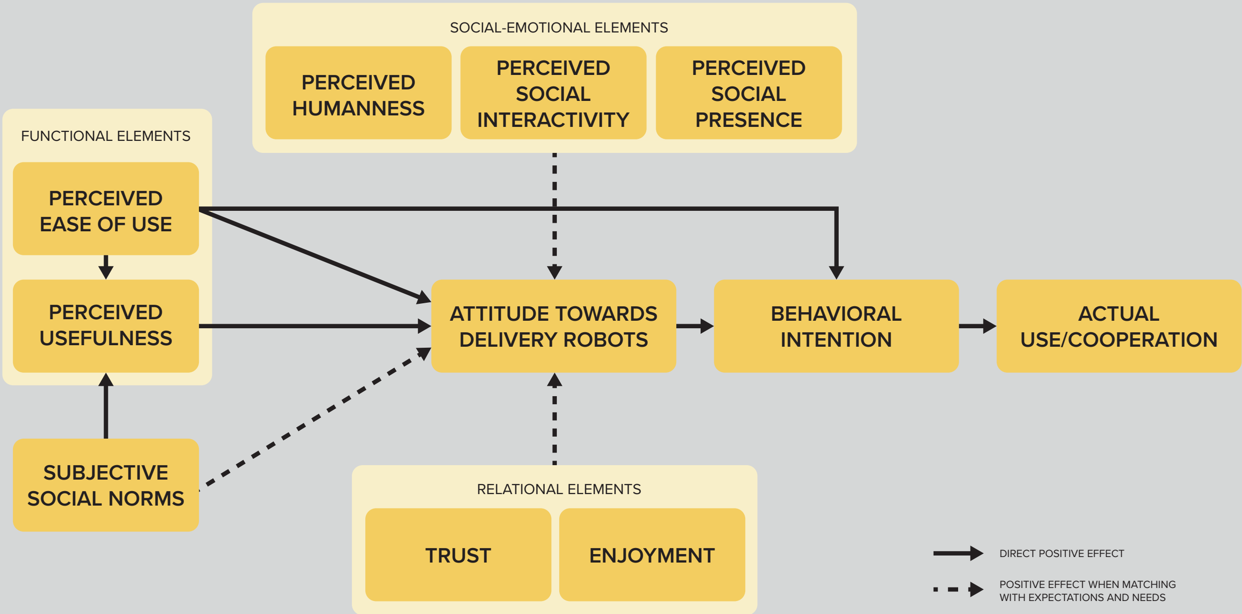


Figure 12. dRAM

Appearance

Humans will have quick first impressions about objects, even without much information available in the environment (Bar, Neta, & Linz, 2006). The appearance of the delivery robot will be one of the first things they see and will therefore influence their expectations. It will influence their attitudes and therefore also their intentions. This chapter dives into the ways in which aesthetics can have a positive effect on pedestrians' attitudes.

The robot's appearance is able to shape the way interaction happens (Kanda, Miyashita, Osada, Haikawa, & Ishiguro, 2008). The form of the robot enables people to understand the robot behavior intuitively. This is also a conclusion which came forward in the pedestrian interviews. While looking at images of delivery robots, much attention was given to the layout of the wheels and how this would influence the robots behavior. Furthermore, Goetz, Kiesler and Powers (2003) suggest that a match between a robots' appearance and its function, improves people's acceptance (Goetz, Kisler, & Powers, 2003). Also, the interviews suggested this. If the participants couldn't retrieve what the robot does, they were less interested in learning more about it and had a lower level of acceptance towards that robot.

Pedestrian interviews - opinions on appearance

For the full documentation of the pedestrian interviews, see appendix D.

During the pedestrian interviews, the participants were confronted with 8 different delivery robots. Their attitudes towards these robots, solely on their appearance can be seen below.

CONTINENTAL

Looks scary.
It looks really (too) robot-like.
It looks most like a human.
It looks like something from Star Wars.
It looks like a monster.
Movement will be very robot-like.
Its movement will not be predictable.
It is here to kill us.
It looks like a spider or dog.
The package can be stolen.
It looks like it can walk stairs.
It will draw attention.

Most participants see the robot as a scary device. They associate it with dogs or spiders and reflect the characteristic unpredictability on it. For improving acceptance, such a mechanical device with legs doesn't seem to be the right direction.

PIAGGIO GITA

It seems fun.
It looks unpredictable.
It looks like a roller suitcase.
Doesn't seem to have much space for parcels.
It looks weird but modern.
You don't see that it is looking.
It probably doesn't talk.
It still needs to prove itself.
It seems maneuverable, which is not calm for pedestrians.
It might not be kind enough for on the sidewalk.
It is not really clear what it is or what it does.
It doesn't look interesting.

The round shape gives people the idea that it can move in all directions and that it is unpredictable. It also doesn't seem logical to transport rectangular boxes in a spherical object. Combined with a very flat design, it is not easy to see what the device is and does.

STARSHIP

It seems fun.
It looks calm.
It looks cute, like Eve from Wall-E.
It seems to fit together nicely.
It looks cool, like a mars rover.
It has a clean design.
It is too small to be safe.
It seems to have a beam with sensors.
You expect it to talk.
It doesn't have enough color.
It looks like it could have a solar panel on top.

Often ranked as one of the preferred robots to encounter on the sidewalk. This is not coming from any association with other products, but mainly because of its clean design. However, multiple participants stated that the device is too small and you can trip over it.

MARBLE

It looks like a fridge.
It doesn't seem playful, not really suitable for the sidewalk.
It is not beautiful.
It is not really intimidating.
It looks professional.
The size seems good and functional.
It will probably not talk.

The Marble robot is boring. Participants didn't start talking about it by themselves. But this might be fine for a delivery robot. It just does its thing, while being quite predictable, because of its large wheel-basis.

POSTBOT

It feels intimidating.
It is too large, you can't look over it well.
The size is good, you can see it through your window.
You don't expect it on the sidewalk.
It looks predictable.
It looks very neat and professional, really German.
It will treat your parcel well.
It looks quite efficient.
You don't see what the front and back is.
You hope that it has seen you and won't hit you.
It will probably not talk.
It doesn't look trustworthy, because it is not easy to see how it moves.

The PostBot was praised by its functional, rigid design. However, it obstructs your vision, which is not preferred. Based on the image there is not much to retrieve about its interaction. It is hard to see what the front is and the lack of sensing technology or eyes makes you wonder if it has seen you.

POSTMATES

It looks fun.
It looks calm.
It looks cute, but not too cute.
His eyes make him look friendly.
It looks like a child wagon, Stint, shopping cart.
It looks clumsy, like Bambi.
The size looks good.
It looks predictable.
His eyes are not too obvious.
You expect it talk simple sentences.
Such a thing on the sidewalk could be a real obstacle.

Much of the PostMates seems to be well designed. It looks friendly, fun and calm. The eyes are subtle and give the feeling that it has seen you. This robot is associated a lot with other products. Its legs look somewhat clumsy like Bambi, and combined with the bucket, it looks like a child wagon or shopping cart. It is not clear if this association is working out positively or negatively.

SEGWAY LOOMO

It looks like a driving printer, fax-machine, a vacuum cleaner, polishing machine.
A driving printer will not improve the world.
It doesn't say much about what it is or does.
It doesn't look like a parcel delivery device.
It doesn't look able to go outside.
It looks unpredictable.

The functional elements (and office background) of this device give the feeling that it will not drive outside. The wheels are not visible and the overall design of the device looks more for in an office. The robot is often associated with a printer, which in this case is a negative thing. People want to be able to see what it does.

KIWI BOT

It looks like a remote-controlled NS train.
The lower part is like a quad or remote-controlled toy, cool but unpredictable.
Its tires are weird, is it going off-road?
It looks angry.
The heart-eyes are not really business-like.
There is nothing wrong with this device.
It looks fun.

The participants were not really decisive about the eyes. They might not be used to anthropomorphised designs yet. A lot of attention of the device goes to the wheels, which are too rough and make it unpredictable. This is coming from associations with other products like quads. The expression of the front might be seen as aggressive. In general, the attitude towards the KiwiBot was not particularly positive. It looks fine, but doesn't match with expectations.

The participants seemed concerned with practical design implications. They preferred a clear communication of how to use the device, for instance, how to unload the parcels. The participants seemed to care about a match between the task the robot is performing and how efficient the design is. Rectangular shapes look more like delivery robots than spheres. This could be linked to the fact that they want to understand what the device is and what it is doing. Functionally efficient designs help the understandability of the product.

The appearance of the robot influences the expected interaction. Especially the design of the wheels is important. Robots with two wheels are perceived as unpredictable. Four or six wheels and a larger wheelbase give the sense of a calmer interaction and more predictable.

No conclusion could be drawn about the level of humanness of the robots. The eyes were sometimes perceived as cute, sometimes they were not perceived at all and sometimes they were seen as not necessary. All robots seemed to be anthropomorphised by the participants. Participants said "him" often and called robots cute and friendly.

Most participants had the tendency to associate the appearance of the robots with products they already know. In some cases, it is clearly a negative thing, since the characteristics of the product that the robot is associated with, are also reflected onto the robot. The KiwiBot looks like a remote-controlled toy. These toys are often going fast and make sharp turns. Therefore, the KiwiBot might also make unpredictable movements or even go off-road. But in the case of the PostMates, which is associated with shopping carts, it is not clear if this is negative or positive. Fewer associations with products can also be a good thing. The Starship is not associated with other products but, is ranked high based on its clean design.

Figure 13. Robots ranked on their preferences.

Product semantics

In the pedestrian interviews it became clear that the participants associate the form of a robot with objects they already know. It is a tendency of humans to categorize products in our head (Kahane, 2015). This is coming from how our memories are categorized in our brain. The association with objects and metaphors are described in the field of design semantics. Product semantics can be used as a tool to use visual and linguistic metaphors, to generate new form ideas for products. Semantics can be categorized in four groups: functional, symbolic, linguistic and evolutionary semantics (Kahane, 2015). Below, the four categories are explained and their references to the findings of the interviews.

Functional semantics
Functional semantics in product design helps to understand how the user should use the product (Kahane, 2015). Technology and science have become very complex. It can be expected that the average pedestrian is not capable of grasping the technologies behind a delivery robot. Aesthetics could guide technology (Hjelm, 2002) by helping pedestrians to interact seamlessly with the robot. In this way the function of the robot is coming from its form.

When functional semantics are applied correctly in the delivery robot, pedestrians will understand quicker what the function of the device is and can form a better expectation about the way of interacting.

In the pedestrian interviews, there was a significant difference in the understandability between the different robots. It seems that the setup of the wheels plays a significant role in predicting the behavior of the robot. The Piaggio Gita, which is a two-wheeled device, looks to be able to pivot around its axis very easily and since it is a balancing device, it might move forward and backward often. It is unpredictable in its movements, which is not desired. A long wheel basis, like on the Marble, expresses predictability. With no visible wheels at all, like on the Segway Loomo, it does not become clear how the device might move. During the interviews, nothing was mentioned about having more than four wheels. A six-wheel setup like on the Starship, might be seen as more rigid in its movement and more predictable. However, the extra benefit over a 4-wheeled device might not be a lot.

Participants in the interviews seemed to have a desire to see how parcels can be retrieved from the device. This is not a function which is necessary to know as pedestrian. However, it gives insight into the overall function of the device and the task it is performing.

Rectangular shapes were associated more with package delivery than round shapes. This is due to the perceived efficiency of handling rectangular parcels. The PostBot seems efficient in delivering. The Piaggio Gita doesn't seem like a delivery robot.

Devices such as the PostBot, Piaggio Gita and the Marble robot, don't have a clear front and back side. This might confuse people or makes them think slightly more about the expected behavior of the robot.

The visibility of sensors and the presence of "eyes", might support the feeling of being seen and the understanding of the robot making decisions on its own. The Marble robot has a large sensor on top, which is clearly visible and the Postmates has obvious eyes. During the interviews, the eyes gave the impression of being seen, but there were no comments on visible sensors. Suggesting that the impression of eyes works more efficient than visible sensors.

"Function follows form: design as a way of creating meaning and comprehensibility in a world of over-functional chaos."
Sara Ilstedt Hjelm – Semiotics in product design

Linguistic semantics

Linguistic semantics are metaphors that come from spoken language, like from well-known sayings (Kahane, 2015).

The current slogan of DHL is: “Excellence. Simply Delivered.” There are no linguistic elements in it that could be exploited in a visual design and it is doubtful if the slogan is widely known. Therefore, linguistic semantics are not further used in this project.

Symbolic semantics

Symbolic semantics use cultural metaphors to increase the appreciation for the product (Kahane, 2015). It is able to influence the “enjoyment” acceptance factor in the dRAM model. This cultural symbolism can be generally understood or specific for one culture.

Some participants of the pedestrian interviews indicated that the PostMates robot looks like a baby stroller. This is due to the position of the wheels and how the suspension forms a triangular shape. It was also indicated that the device looks like a shopping card, due to the relatively high position of the body, compared to a more open design of the suspension. To give another example of symbolism, the Segway Loomo was perceived as a printer in offices. This was seen as a negative symbolism, since participants didn’t expect printers to drive over sidewalks. The symbolism likely comes from the vertical design, the hidden wheels, the white plastics and the trays.

Symbolic metaphors can be applied to the delivery robot to make people associate the device with a human postman, or a delivery van. Another opportunity could be to give an association with an already existing device on the sidewalk that people accept, like a baby stroller.

However, devices with less symbolic semantics can also be successful. There is no fixed form language that defines the category of delivery robots, so a totally new shape can be designed, which may become the archetype of this category. A good example of less utilization of symbolic semantics is the Starship robot. It is perceived as high-quality design, but there is no conscious perception of a metaphor.

Evolutionary semantics

Evolutionary semantics are adoptions of product characteristics from previous artifacts or classes of products (Kahane, 2015). All product forms have developed over time, based on the previous products that users have experience with. Public acceptance is depending on this recognition with other objects.

Evolutionary semantics are difficult to apply on delivery robots, since most people have never seen a product from this category. However, it is possible to look at similar products in delivery practice, robotics, media and vehicle design, that might form the basis for the perception of people about delivery robots. See figure 14 and figure 15 for an overview of product groups with potential evolutionary semantics.

As can be seen in figure 14, a lot of devices that are used in the logistics sector have rectangular shapes, with little to no rounded edges. This is off course very space efficient. It can also be seen that the parcel compartment is visibly separated from the carrier. One reason for this is that the parcel compartment is retrofitted to the vehicle to save money, or in case of the container, to use different types of carriers for the same container. A lot of carriers have a defined rectangular shapes, but have rounded-off edges, which makes a more soft design. This is good visible with the Deutsche Post vehicle, the truck and the Picnic vehicle.

The differentiation between carrier and container can be exploited in the design of the delivery robot, to create a evolutionary association with delivery practice. The same counts for the rectangular form language.

DELIVERY PRACTICE

ROBOTICS

Figure 14. Potential evolutionary semantics in delivery practice and in robotics.

During the design of the delivery robot, it is possible to promote an evolutionary association with the category of robotic products. However, it is doubtable if there is a specific design language for this category. The two robot images on the left of figure 14 are of functional products, which mainly use geometric shapes. The round shape of the Roomba communicates that it is able to pivot around itself. The round blue shapes in the robotic arm communicate movement around that point. These two products don't have any deliberately designed anthropomorphic elements.

The three images on the right are of more anthropomorphic robots. They use combinations of geometric shapes to resemble human or animal features. For instance the head of the Aibo dog, which is made of two spheres merged together. The Pepper robot also has a sphere as starting point of its head, which draws to the side to form a very flat head. This distinct feature might be implemented to make very clear that it is a robot. This elimination of doubt, might take away some nerves that people might have.

These and other robots on the internet also show that a much used color for their embodiment is white or grey. There doesn't seem to be a particular reason for this. However, if pedestrians associate a delivery robot with the robot category, they might reflect some of the characteristics onto them. For instance, the expectation of more social intelligence.

MEDIA

AUTOMOTIVE

Figure 15. Potential evolutionary semantics in the media and transport industry..

A third possible association category consists of robots in popular media. They might have formed expectations in peoples' head about how a robot looks like. Based on the images in figure 15, some robots consist of very round shapes and others have a very mechanical embodiment. The third image from the left shows a scene from Wall-E. This popular movie shows two very different robots. Wall-E is very mechanical, but can express emotions with its cameras, grippers and posture. Eve has a very abstract shape, but can express emotions with her eyes and posture. This movie made a lot of people feel empathy for both characters. This demonstrates that very high level of empathy can be drawn from robots that don't look very human and have no legs. Expressing emotions with eyes seems very effective, especially combined with movements of the body.

If higher levels of humanness are preferred in the delivery robot, inspiration can be retrieved from how media uses expressions of eyes, as well as their round features of the head.

The last category that could logically have evolutionary association is the automotive industry. Similarities between the delivery robot and this category are that they both move in the urban environment, have mostly four wheels and transport people or goods. These similarities could be a reason to implement characteristics from this category. However, cars are often used as personal status symbol and are made for high speeds, which influences their formgiving.

Since the delivery robot is a new product category and might need to communicate other qualities like friendliness or safety, it doesn't seem like a logical step to take a lot of inspiration from this category. However, specific functional elements from the delivery robot, like how the packages are unloaded, how it makes itself visible at night and how to communicate that it is sensing the environment might have evolutionary links to the transportation industry. The previous version of the Google self-driving car has a big lidar sensor on top of the car. This is practical to get a 360 degrees view of the surrounding, but also communicates to people that it is an autonomous car and might give some reassurance about its capability. The designers also deliberately made the overall shape and the forms of the eyes look kind, to make the robot more approachable and trustworthy.


TWIZY


The Power of Dreams

Appearance discussion

To analyze appearance, an semantics approach was taken. This choice was made based on the importance of association during the pedestrian interviews. During the design process, inspiration will be taken from product semantics theory and existing products. Making the design aesthetically pleasing will be done based on designers insight.

It should be noted that the results of the pedestrian interview are from 9 participants. The opinion of the larger population can differ from this.

Appearance conclusion

For the design of the delivery robot it seems most logical to use functional semantics and evolutionary semantics.

Functional semantics seem very important, since the product is very novel. People still need to learn what the device is and how it operates. Improving the functional semantics would improve the functional elements in the dRAM. The participants from the interviews showed more preference in functionally efficient designs than appearances they could not relate with delivery practice. This means that functional rectangular shapes are preferred over very rounded shapes. The visibility of the wheels made the robot more understandable. The wheels also improve the perceived ease of use, since robots with more than two wheels look more predictable. Also the type of wheels are important. Rough wheels on a small device were seen as unpredictable, due to the association with remote -controlled toys.

For the evolutionary semantics, it can be assumed that inspiration should only be taken from products or categories that reflect positive associations onto the delivery robot. A good example could be associations with the delivery practice category, since the delivery robot fits within the same category. These evolutionary semantics will as a side effect work as functional semantic, since it communicates what the function of the device is and how to use it. Products in the logistics category are characterized by their rectangular containers, combined with more round carriers. In some cases, this differentiation is a functional semantic that shows that the container can be separated from the carrier.

Using semantics in the design can have positive and negative effects. Hekkert and Cila (2015) explain that by careful mapping, the designed object inherits the meaning of the source object. Therefore, the goal of implementing semantics should be determined and potential source objects should be selected based on relevance to this intention.

There are three hypothesis about product association:

- Associations might induce product characteristics to reflect onto the robot: negatively or positively.
- Associations might induce expectations, which can lead to disappointment when not met.
- No association gives a blank canvas for new interactions and attitudes, but takes more effort from users during introduction.

During the design process, care should be taken to understand the effect of the designed semantics. It could turn out that using less symbolic or evolutionary semantics in the design, like the Starship robot does, is more effective, since it gives a blank canvas for new ways of interacting.

Pedestrian-robot interaction

Pedestrians are highly unpredictable, since they maneuver around obstacles, are distracted by their phones and other people and might change their destination if they see something of interest. To create a starting point for later interaction testing, literature is reviewed to gain insights into the unwritten rules of walking on the sidewalk. Furthermore, the pedestrian interviews gave insights into the behavior that is expected from the robot if it maneuvers over the sidewalk.

Social forces

Helbing and Molnar (1998) describe that the behavior of pedestrians is mostly automatic, this is possible since most scenarios are in line with past experiences. During walking, pedestrians experience internal motivations for a certain behavior, based on “social forces” they experience from their environment. Attracting forces are coming from points of interest in their environment. Repulsive forces are coming from other pedestrians and borders. The unpredictability of pedestrian behavior is partly coming from attracting forces that can arise suddenly, for instance in the case of a sudden friend on the other side of the street. The social forces can be described by mathematical formulas, in which the sum of all forces determines the walking direction and speed, as can be seen in figure 16. This is called the social forces model in literature.

Desired velocity in the goal direction
Pedestrians try to reach their area of destination in the most comfortable way, which is by avoiding detours and taking the shortest path (Helbing & Molnar, 1998). They preferably walk with a desired velocity. Encountering obstacles will reduce the actual velocity. When a free path is available again, the actual velocity increases again, after a short relaxation time (e.g. 0.5s).

Distance towards people and borders
Depending on how busy it is, a pedestrian keeps a certain distance towards other people and borders, because of the repulsive forces that he experiences. The area just in front of the pedestrian is of the highest importance to him, since this is needed for his movement and next step. Forces are applied based on a field around the pedestrian, that can be seen as an ellipse that extends into the direction of walking (Zeng, Yu, Chen, & Wang, 2017). Everything behind the pedestrian, which is outside of the field of view has a weaker effect (Helbing & Molnar, 1998). The closer pedestrians get to your sphere, the stronger the repulsive forces get, due to the increased discomfort (Helbing & Molnar, 1998). This increase in force works exponentially. Borders also apply repulsive forces, since the pedestrian has to pay more attention to avoid danger of getting hurt.

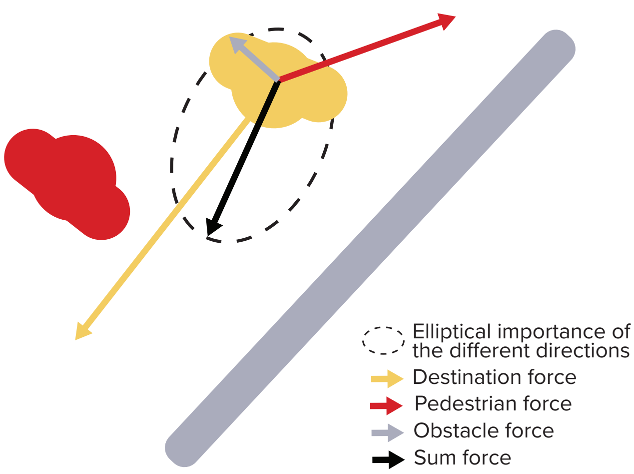


Figure 16. Example of a pedestrian situation and its social force vectors.

Attraction affects
Attractive forces are coming from points of interest, or from other people in a pedestrian group (Helbing & Molnar, 1998). The force decreases over time, due to the decreasing interest. Zeng et al. indicate that other pedestrians can induce attractive forces, if they are moving in the same direction as you. This lane forming especially happens when pedestrian density increases.

Social forces conclusion
The robot could be able to operate with social forces as the leading factor for its behavior. Its behavior would feel more human-like and is therefore more predictable and decreases the learning curve of how to interact with the robot.

Social forces could be used in the robots logic, since all computation is based on forces “experienced” by the robot itself. It is also possible, with sufficient computing power, to calculate how other pedestrians are experiencing their surroundings and predict what they are going to do in the near future. The robot is then able to adjust its behavior to for instance prevent other people from having to slow down.

If the maneuvering of the robot is based on the same logic as humans, there are still important differences that need to be taken into account. For instance the difference in moving. Humans are very flexible and can pivot around their axis, while some wheel setups of the robot only allow it to have a minimal turning angle, like a car. The social forces logic would need to be adjusted to this difference. Also how pedestrians experience the robot, compared to other pedestrians, is different. The appearance and behavior of the robot will determine how much social force pedestrians experience from the it. Pedestrians might experience large repulsive forces if they perceive the robot as unpredictable or dangerous. The robot also has the potential to evoke a smaller social force than pedestrians, since they know that the robot won’t be angry if you step into its “personal” area.

Pedestrian interviews - opinions on interaction

During the pedestrian interviews the participants were shown three videos of pedestrian-robot interactions. See appendix D for the full research method. The results in figure 17 show there was the convincing opinion that people standing still on the sidewalk obstructing a robot, should let it pass. All participants suggested that the robot could use sound to signal that it wants to pass. The participants also indicated that the robot should hold a comfortable distance with people, since it might become uncomfortable otherwise.

Two of the participants indicated that the robot should give people priority and be subordinate. Seven participants reacted positively on a robot taking priority when arriving first at an intersection. Based on what people expect, the robot could therefore have (almost) equal rights to pedestrians.

Based on this, it can be concluded that it is likely that people expect somewhat human maneuvering behavior from the delivery robot. One participant said that as a pedestrian you don't want to learn any new mental models. Therefore, you expect the robot to fit in with the same mental models that you already have.

PARTICIPANT	OPINION ON BEHAVIOR
1,2,3,4,5,6,7,8,9	People should step aside if a robot approaches.
1,2,3,4,5,6,7,8,9	If the robot comes very close, it becomes uncomfortable or intimidating.
1,6	The robot should be subordinate.
1,2,3,4,5,6,7,8,9	The robot could use sound to signal people that he wants to pass.
5	The robot should know how to interfere people in different situations.
6,8	You expect the robot to behave by the same rules as people.
1,2,3,4,5,7,8	Scenario 3 was solved fine.
6	In scenario 3 the robot should have waited.
9	In scenario 3 the person should have waited more patiently.

Figure 17. Potential evolutionary semantics in the media and transport industry.

Future vision

The research up to now has been mostly about analyzing current delivery robots and current attitudes of people. However, our relation with technology and robots will change in the future, which highlights the importance of trends and developments research. There might also be ways of relating with technology that is significantly different that what current delivery robots provide. This chapter goes into the results of a Vision in Product Design (ViP) method, that describes a more desirable future context and how the robot fits in there.

The ViP method, which can be seen in figure 18, starts with a preparation phase that consists of deconstructing the past context. Current delivery robots are analyzed, first on their form and consequently on their interaction with people. The deconstruction phase ends with stating what design choices can be linked back to the context at that time. E.g. robots often have human facial elements, since people are still a bit afraid of robots and a robot with eyes is less scary than one without.

In the design phase of the ViP method, future context factors are researched, to describe how the future might look like. This includes trends and developments. These factors form the bases for a storyline. Based on the factors and the storyline, a statement is defined of what the design should offer. This statement often addresses future needs of customers and shapes a future which is most desirable.

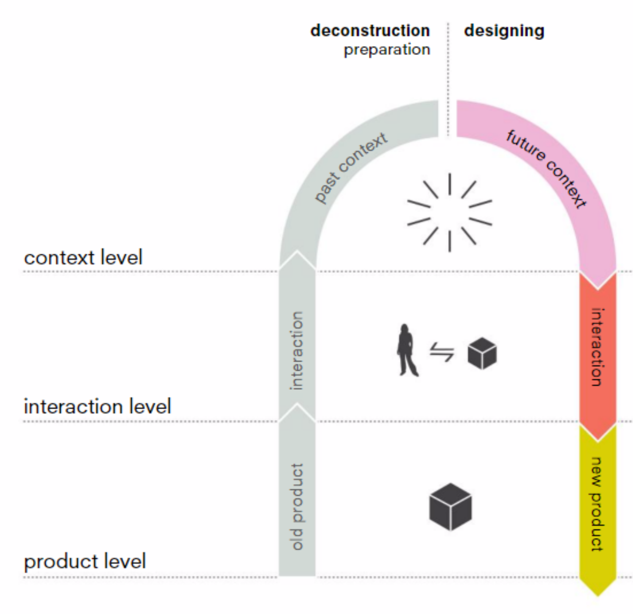


Figure 18. Diagram of the ViP method, going from bottom left to bottom right.

Past products

There are three kinds of delivery robots currently on the street. The ones that attempt to look approachable, the ones that try to be business-like and the robots that are functionally efficient.

The approachable robots have soft shapes and have a display or distinct lights that are easily interpreted as their eyes.

Figure 19. Approachable robots: KiwiBot and DRU

Business-like robots have a well thought through design, but are less approachable, since they have less facial elements.

Figure 20. Business-like: Starship and Amazon Scout

Functionally efficient robots have a very rectangular form language. Their mechanical parts and sensors are often visible and their level of humanness is very low.

Figure 21. Functionally efficient: Marble and FedEx

Past interaction

Current delivery robots drive over the sidewalk at the speed of pedestrians or slower. Often they have wheels which are not able to steer, but because of the small size and low weight of the robot, it can rotate by moving the wheels at different speeds. This can results in some shaking of the body if it needs to overcome the friction forces on the wheels. This gives it a somewhat clumsy behavior. These robots are able to maneuver around their axis, which is functionally efficient. However, turning of the wheels can be an indicator that it is turning or going to turn.

Most robots don't use dedicated indicators that communicate its intentions (intent indicators). One of the few is the robot from FedEx, which has a display on the front and back, which indicates that it is driving or standing still. This display is also used to communicate to customers and to say hello to other pedestrians. The KiwiBot has a display on the front with animated eyes. It indicates its intent to stop by transforming each eye into an "x". Further interactions are more playful and indicate that the robot has seen you by looking in your direction or simulate affection by showing harts. Due to the vast amount of animations it can become confusing, especially for elderly people. People need to learn what animations are important for them and which not.

In case of the DRU from Dominos, its playful character is integrated into other interactions that customers have. For instance, his virtual entity helps you in the App with ordering pizza, in the form of a chat-bot.

Past context

One of the context factors that describe why delivery robots are the way they are, is the relation that people and especially companies have with automation. Automation is involuntarily for the general consumer, since it is the decision of companies. Companies value automation highly, because they need it to make profit and to create competitive advantage. They tend to strive for as much automation as possible. In the delivery robots, this expresses itself in fully autonomous concepts, where human operators play a supporting role in the transition phase. Once the robots are functioning reliably, the operator, which is either directly supporting the robot or teleoperating, will not be needed anymore. Sometimes a human is operating at a distance. The system where the KiwiBot operates in is a combination of humans and robots, since that is the most profitable right now. But the CEO states that if they can automate further, they will do so (TechCrunch, 2018). By the general public, robots are seen as a thread to employment.

Another context factor that explains the design of the robot is how other technology is shaped. The word "robot" makes you think of humanoids seen in movies and at technological showcases at fairs. However, many robots used in practice are industrial robotic arms and Roomba's. In the western culture we are not yet accustomed to having humanoid robots around us. This can explain the more vehicle like delivery robots currently employed. The Continental dog-like robots are an exception, but they are also seen as scary, as found in the "pedestrian interviews". Also human-like interactions with robots are not widely adopted, which explains the mechanical interactions of current delivery robots.

Future context

In this section about the future context, trends, developments, states and principles are combined to create a vision about a possible future. As a designer you can then design for this future or actively deviate from it. There are subjective decisions made that inevitably resembles how the designer sees the world. See figure 22, for future links between them and there interconnectivity, which are called dimensions.

Dimension 1: Control and technical limitations
The need for control over ones situation is a basic principle of life. We do not always actually need to be in control, but we at least have to feel a sense of control. However, it is unlikely that delivery robots will create a sense of control in pedestrians. Their artificial intelligence system is not yet able to recognize detailed human behaviors and will therefore not be ideally adapted to cooperate with humans. Pedestrians still need to adapt to cope with the behavior of the robot.

When we seek for control, we balance having power and having choice (Siegel, 2008). If we can have great power, we don't need much choice. If we have much choice, the need for power is less. Pedestrians don't have much power when it comes to the robots existence on the sidewalk, but they can have some choice and power over how pedestrian-robot interaction situations are resolved. Pedestrians take the initiative to walk how they want and the robot should be intelligent enough to adapt itself. The robot should then be smart enough to recognize also the more subtle behavior of humans. If, due to technical restrictions, this is not possible, there should be searched for other ways in which pedestrians can indicate their intentions to the robot.

The third way of establishing a sense of control is if there is a high level of trust (Siegel, 2008) in the robot, for instance by making the robot highly predictable.

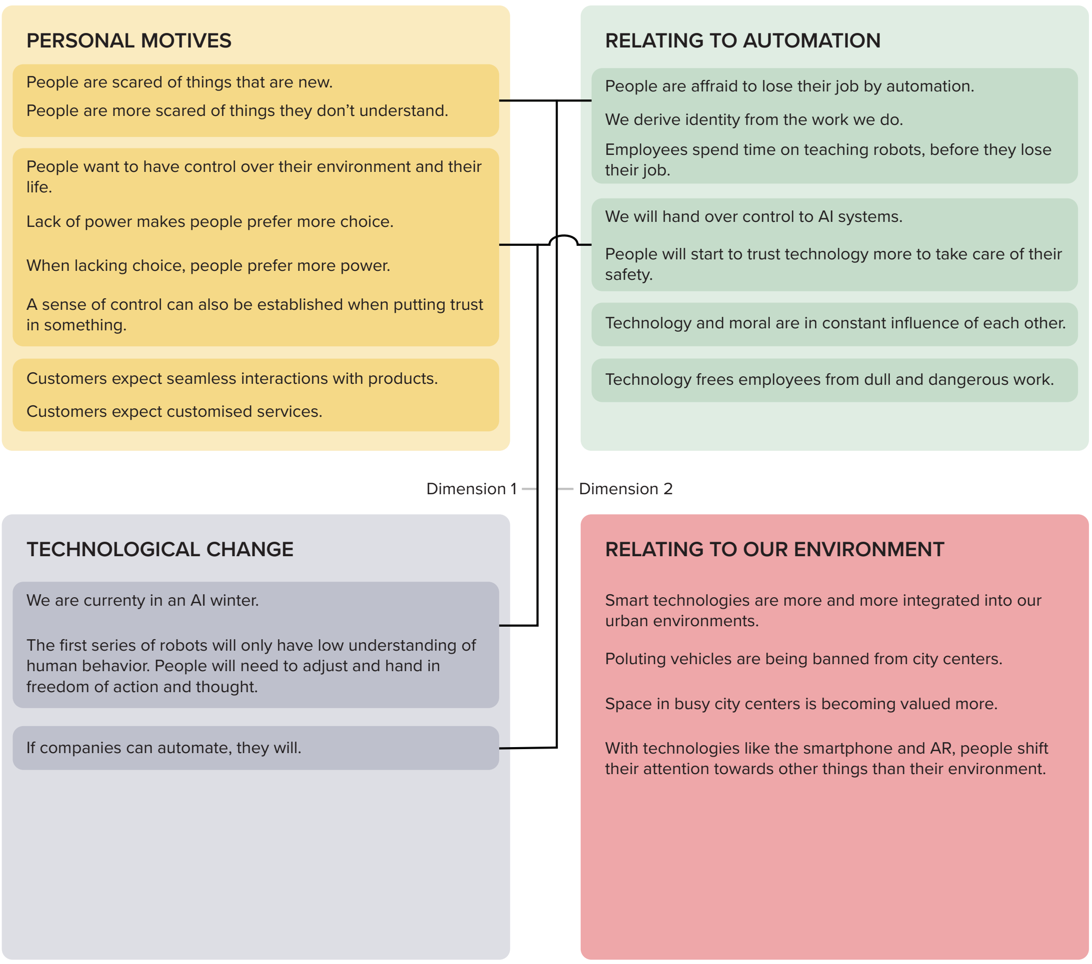


Figure 22. ViP future factors and three dimensions with conflicting factors.

Dimension 2: Relation with automation
A principle is that companies are constantly searching for more efficient ways to produce. Delivery robots are a good example. If companies are able to automate the last-mile, they will do. There is nothing wrong with that, but it is in contradiction with some needs of society. People are afraid that automation will endanger their job and put them unemployed. This endangers their identity, since part of our identity is derived from the work we do. People are always hesitant of allowing new things that they don't understand into their lives. However, they don't really have a choice if logistics companies roll out their robots.

Since robots haven't yet established a fixed position in society, a large company like DHL could have an important role of establishing a positive role of robots in society. Delivery robots could preferably have a supporting role in the system. One in which they are helping humans to achieve higher levels of productivity, instead of the other way around. The visual role of an operator, in the early phases of implementation, is crucial. Ways could be found to reduce the feeling that the operator is there to support the robot. The way a delivery employee works together with the robots is crucial as well. A delivery employee visible on the street, which has a dominant role over the robots could give pedestrians the feeling that humans are still in control over their environment.

VIP Design statement
"I want people to feel a sense of control when interacting with robots, in which they can actively take initiative in situations."

This means that pedestrians should not be in a position where they constantly have to react and adapt to the behavior of the robot. Pedestrians should be able to take initiative, so they can shape situations to their needs.

Future interaction

Interaction statement
During the pedestrian-robot interaction, both parties should experience a *smooth understanding* about each others actions and intentions.

Future product

In the design phase, solutions will be found to giving a sense of control to pedestrians, while having smooth understanding between the robot and pedestrian. Below are some product qualities that describe "smooth understanding"

Product qualities for "smoothness"
- Effortless
- Natural
- Flowing
- Low investment

Product qualities for "understanding"
- Flexible
- Light
- Inclusive
- You understand the robot
- The robot understands you
- Considered

Design goal

A lot of insights have been gained during the research phase. These have been compiled into a design goal, product requirements and wishes, that can be seen below. They form the backbone of the design phase.

Design a delivery robot that has a functionally efficient design, provides instinctual interaction for pedestrians and gives them the feeling of control over their environment.

Functional efficient design
A functional efficient design improves the perceived usefulness, since it makes it easier to see what the robot is and what it is doing. The perceived ease of use is also perceived as higher, since the robots shape communicates how it operates and creates the right expectations about how it will react during interactions.

- The height of the device must be enough to have sufficient capacity, but not too much to block the view of most people and to feel too dominant.
- The robot should have more than two visible wheels, with an appearance that improves the predictability.
- The robot should visibly take good care of the parcels, by for instance remove the concern about parcel theft.
- The robot should be inclusively designed, which should also show in the way parcels are retrieved by customers.
- The gap between the robot's characteristics and that of humans could be minimized, so pedestrians accept a mimicking of human behavior as well.

Instinctual interaction
To maximize the acceptance of pedestrians, the robot should provide pedestrians with an instinctual interaction that takes minimal effort. Pedestrians should be able to use their current mental models about sidewalk behavior and technology interaction, to interact with the robot.

- The robot should mimic most of the maneuvering of humans and the pedestrian rules, to make it more predictable.
- The appearance of the robot must demonstrate high predictability by using non-verbal communication or more machine-like intent indicators.
- The robot should signal pedestrians that are blocking the sidewalk, in a clear but non-intrusive way.

Control by pedestrians
As described in the future vision, the robot should give pedestrians the feeling of control while interacting. It is a basic principle of life that people have a need for this.

- The pedestrian could get extra control by having a dedicated way of steering the behavior of the robot.
- The pedestrian could get the feeling of control by designing the robot to be highly predictable and trustworthy.
- The feeling of pedestrians while taking control should be described by a "smooth understanding".

Social-emotional elements

- The robot should show low to medium amounts of humanness, since the Dutch population feels more comfortable with that.
- The robot's level of humanness should be in relation with its social intelligence, to prevent disappointments of unmet expectations.

Relational elements

- The robot could spark joy by its appearance and interaction, but should easily be ignored if pedestrians are not interested.

Intended semantics

- The robot should have functional semantics, to maximize perceived usefulness and ease of use.
- The robot could have evolutionary semantics with delivery practice products, to improve the perceived usefulness.
- The robot could have evolutionary semantics with autonomous vehicles, to improve the perceived ease of use.
- Other symbolic semantics may be used to inherit intended characteristics, but undesirable associations should be prevented.

Other

- The robot could deliver (additional) services to pedestrians, to boost perceived usefulness.

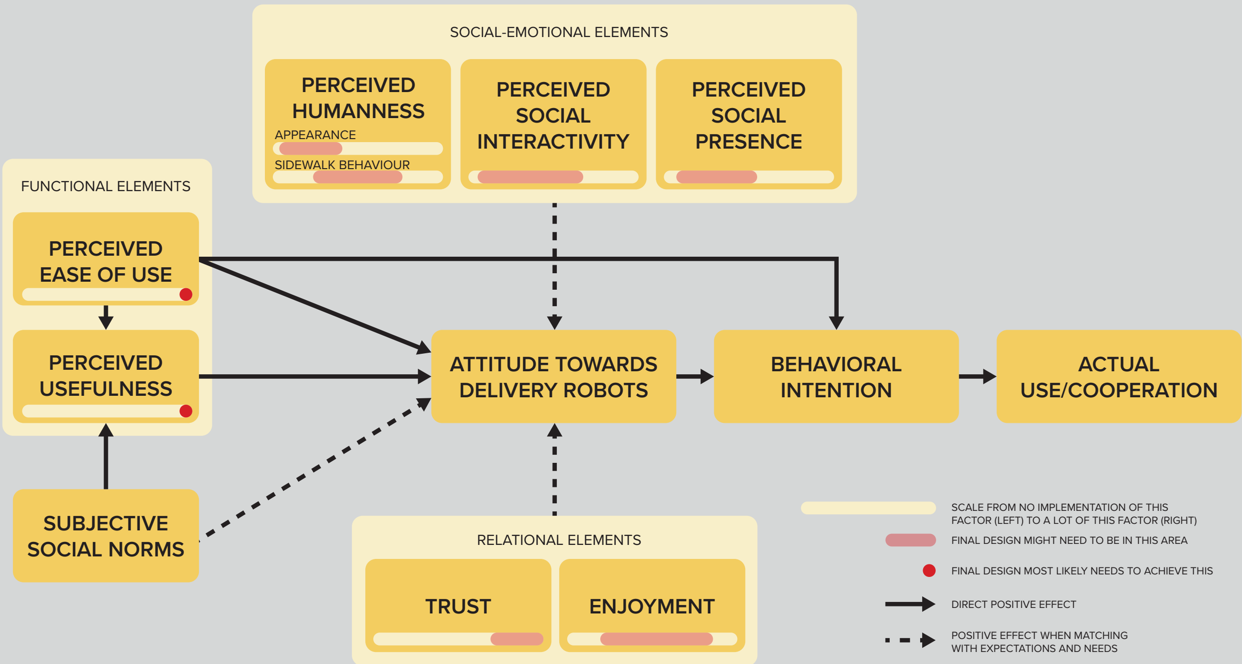


Figure 23. dRAM model with estimations about to what extend the factors want to be perceived by people. Towards the right of the scale, the more of that factor should be implemented in the design. The estimations might change based on future insights.

Design phase

In the design phase, three directions will be proposed that are in line with the insights from the research phase. One of these directions will be chosen and used for further interaction testing, to find a desired behavior of the robot and the indicators that communicate what the robot is intending to do.

Figure 24. Development of the robot's formgiving. Starting with ideation sketches, iterations, three idea directions, virtual prototypes and the near final design.

Intent indicators

When encountering delivery robots for the first time, pedestrians will need to learn in what way the robot behaves. It is most preferred that this learning period is as short as possible and therefore that the understanding is intuitive. Combined with a predictable maneuvering, this could be established by using indicators on the robot that show what its intentions are. These intent indicators could come directly from human behaviors, but also from well known products like cars. Below, possible intent indicators are displayed, including a first evaluation.

In figure 25 till 34, ideas I1 till I10 can be seen. In order for an intent indicator to be intuitively understandable, it should fit with already existing mental models that pedestrians have. For instance, head and body movements, since pedestrians use this as well. Or the robot could have an association with cars, in the case of a blinking orange light.

It should be taken into account that concepts like I1, I2 and I7, which have a display, could more easily be adapted to the needs of pedestrians. I1 and I2 could even be used interchangeably, depending on the situation. It could provide functionalities when interacting with customers.

Intent indicators that use led strips, like I3, I6, I8 and I10, are more rigid in their design, but are easy and cheap to implement. They give a more mechanical feeling to the robot, compared with intent indicators that use eyes.

Some indicators that use their movement to show intent, like I5 and I9 could be implemented on top of another indicator. It is important that the combinations are congruent. Indicator I5, could better be implemented onto a robot with more humanness, like I1.

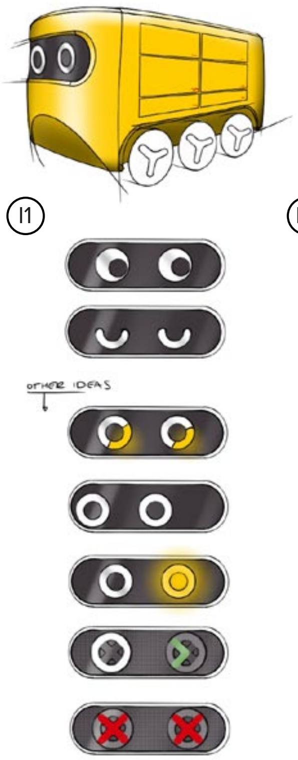


Figure 25. A display on the front side with eyes that look in the direction in which it is about to go. Drowsy eyes indicate that the robot keeps parked.

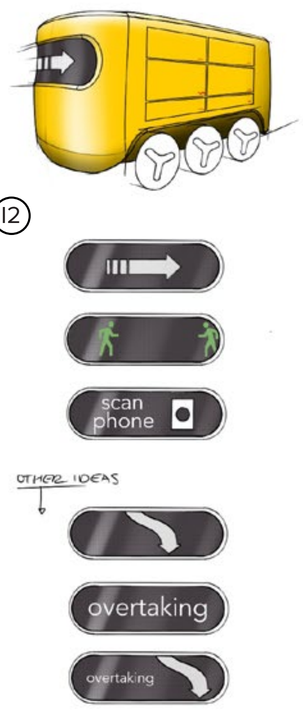


Figure 26. A display that shows an arrow when it is about to turn and a walking pedestrians animation if it will wait till everyone has passed.

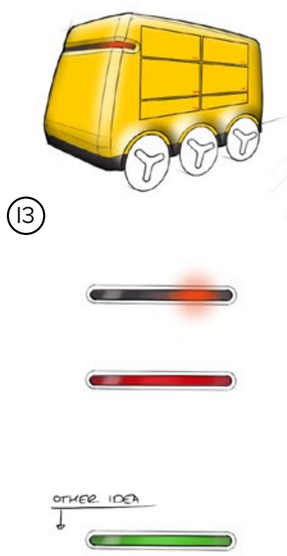


Figure 27. A blinking orange light as association with car lights. Red tail light when braking.

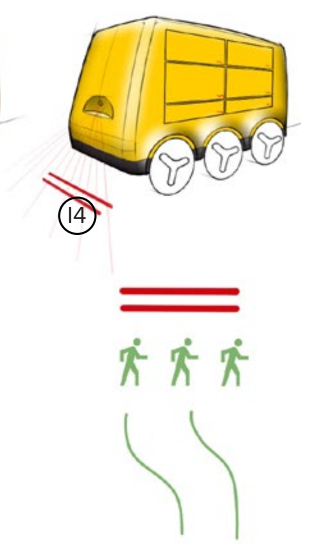


Figure 28. Projected lines on the ground that show its path.

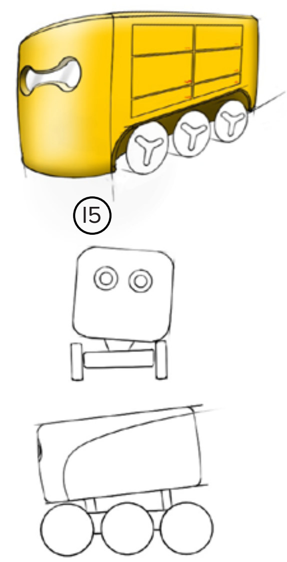


Figure 29. The body moves sideways, just before setting in a turn. The robot's body drops lower when it is waiting.

Technical feasibility is important as well. I4 could be one of the best indicators, since it not only indicates that it is turning left, but also that it will turn right over a meter. However, projections on the ground are hardly visible during daylight and are therefore not a feasible option.

In figure 35, all criteria are weighted and the ideas are rated. The most promising ideas seem to be to use eyes which look at the direction which it is about to go to and to use a led strip with a linear animation when it is accelerating or turning.

CRITERIA (+ factor of importance)	I1	I2	I3	I4	I5	I6	I7	I8	I9	I9
Understandability (30)	6	3	8	10	5	7	2	6	5	6
Fitting with current mental models (20)	7	3	7	3	8	7	1	3	8	3
Technical feasibility (15)	8	8	10	1	6	10	7	9	6	10
Adaptability over time (10)	9	9	4	7	6	5	9	4	6	3
Subtleness (10)	8	6	9	6	10	8	5	6	9	6
Cost price (10)	7	7	10	5	6	9	2	8	9	9
Ease of development (5)	8	8	10	3	5	9	7	8	6	8
TOTAL:	720	530	810	690	645	765	380	595	690	705

Figure 35. Evaluation of the intent indicators.

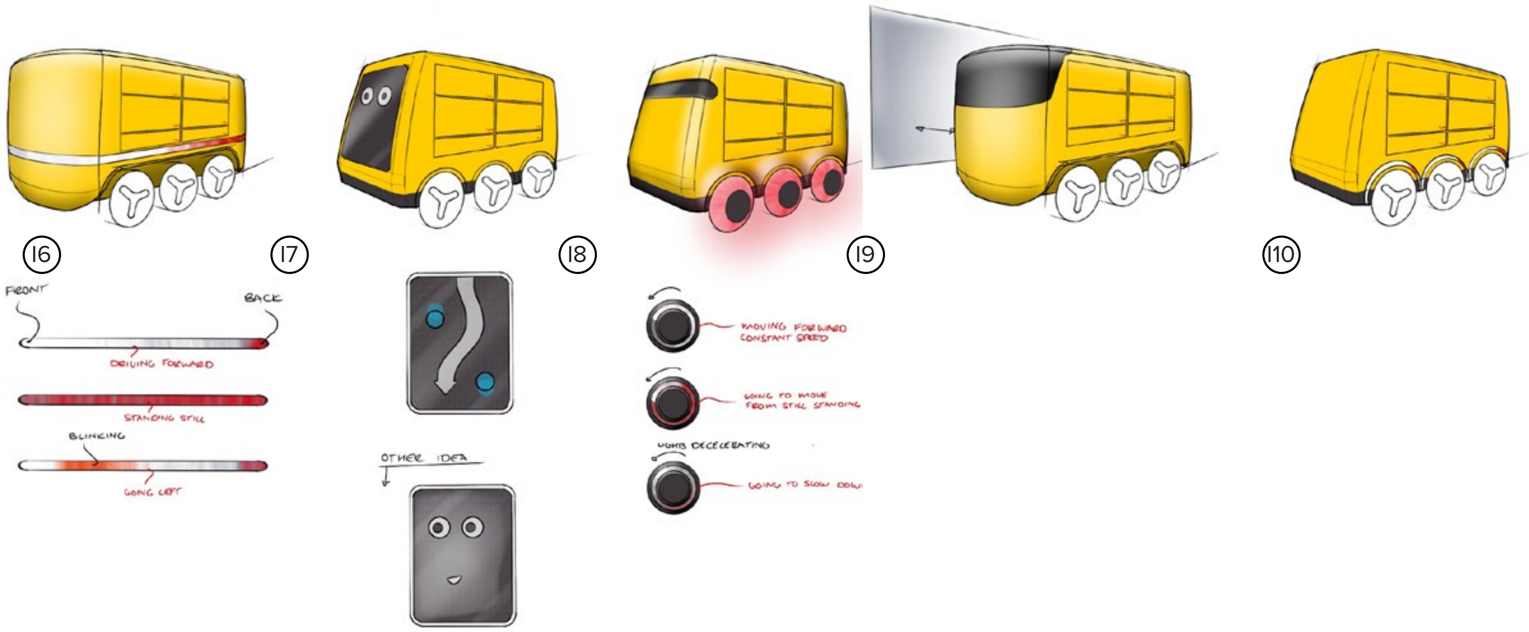


Figure 30. A dynamic led bar, with orange animation to show that it is about to turn. A white linear animation can be used for intending acceleration and red for deceleration.

Figure 31. A large display shows all entities in the environment and its path.

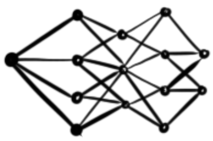
Figure 32. A red and white animation on the wheels shows acceleration and deceleration. Orange blinking light shows turning behavior.

Figure 33. The robot stays close to the border to indicate that it will keep on going straight. Further away from the wall indicates a possible dynamic action.

Figure 34. Leds around the wheels indicate acceleration or deceleration by a white or red animation.

Control during interaction

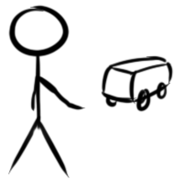
As described in the chapter about the future vision, pedestrians should have a high sense of control during the interaction with delivery robots. This chapter describes some ideas that could establish this.



Since the feeling of control increases once there is a high level of trust, the robots behavior could be optimized to respond the most predictable to every situation. On top of basic positional and movement data from entities in the environment, the robot could be programmed in such a way that it senses all the small cues with which it can perceive the intentions of pedestrians. It should be noted that these cues can be very small, like looking in a direction or turning a foot. The cues are also not exclusive, for instance turning of the head, which could indicate turning towards that direction, but could also be interest in a shop window. A machine learning model should be trained with lots of data and still there could be a significant percentage of wrong predictions.

Pedestrians have a feeling of control, since they know that the robot understands their movements and will adapt its behavior.

Pedestrians could give immediate feedback on the robots functioning by speech. To make contact with the robot, a physical connection could be made by placing a hand on the top of the robot, before talking to it. The feedback will be processed by a teleoperator. This way of giving feedback gives a feeling of control, because pedestrians can have influence on the development process of the robots behavior. However, this does not give control on the interactions with the robot at that instance.



Since it might not be technically feasible for the robot to always recognize the intentions of pedestrians, there could be a dedicated hand gestures. For instance a movement of the pedestrian's hand or arm to indicate that he is going in that direction. This would only be needed in situations in which the pedestrian really benefits from an adaptation from the robot and there is no other way in which the robot can perceive this.

Speech is a natural way of interacting with other pedestrians to solve scenarios. An example is when two pedestrians move towards each other and accidentally pick the same side, forcing both to stop. This could be solved by speech. In situations like this, or where pedestrians could really benefit from an adaptation of the robot, speech could be used. However, this only works on smaller distances and in environments without much noise.

CRITERIA (+ factor of importance)				
Low investment for pedestrian (25)	10	7	2	4
Intuitive (20)	10	6	7	5
Technical feasibility (15)	6	8	9	6
Safety (10)	8	8	3	8
Functional at right distance (10)	8	9	1	5
Not bothering other pedestrians (10)	10	7	6	4
Applicability in different situations (5)	10	5	8	3
TOTAL:	850	680	465	475

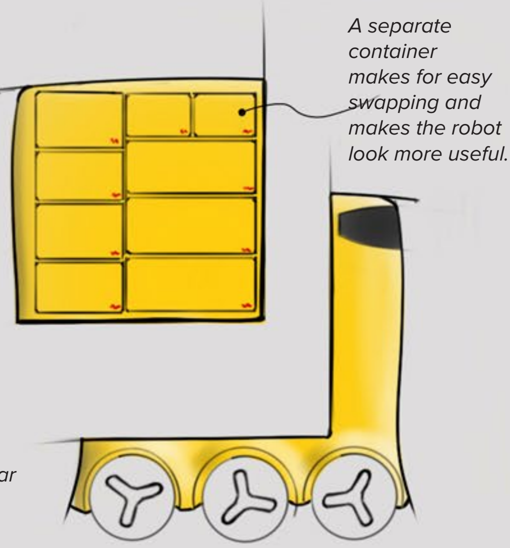
Figure 36. Evaluation of the control interactions.

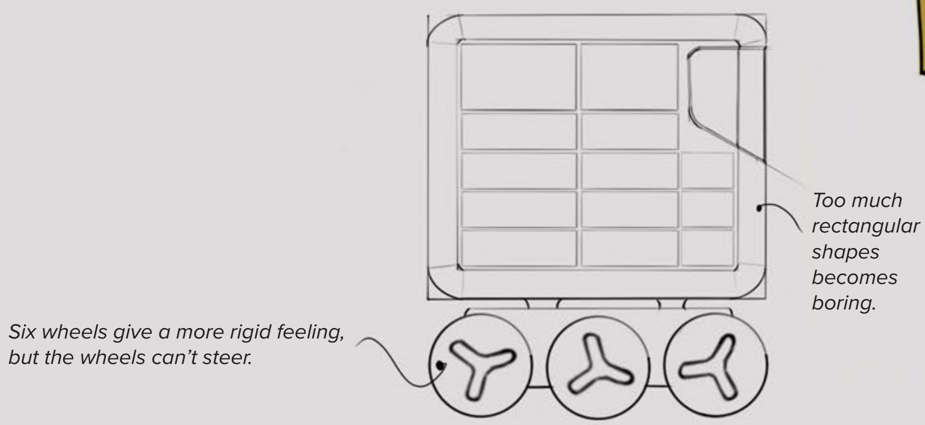
See figure 36, for an evaluation of the four ideas, with the weighted criteria method. Optimizing the intelligence of the robot to take initiative in solving situations the best way as possible, has the most potential. It does not take any effort from pedestrians. This method is depending on the robots competence of its behavior to create trust in pedestrians and should therefore be equipped with a sufficiently capable recognition and processing system.

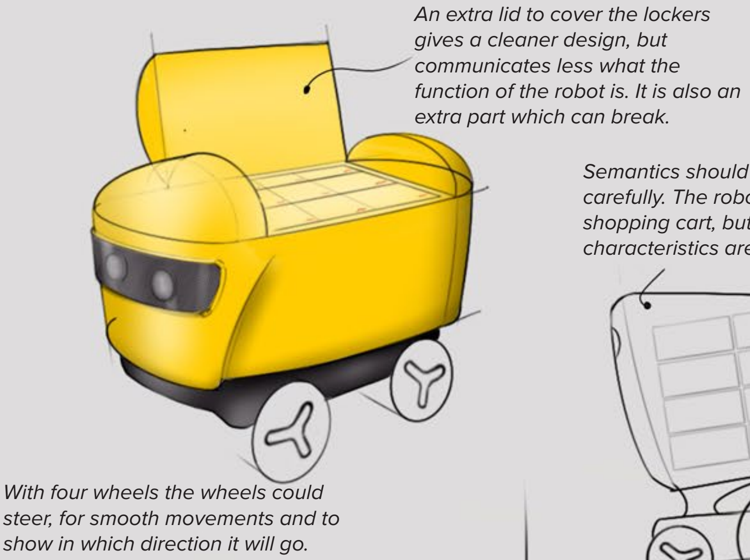
Using gestures to communicate with the robot, could have a supporting role in solving some complex scenarios, while giving control to pedestrians. It is a relatively low investment for pedestrians, but has direct effect on the feeling of control. With gesture communication, it is not only the robot which can indicate what it is going to do, but also the pedestrian. This gives a more equal role in the human-robot communication.

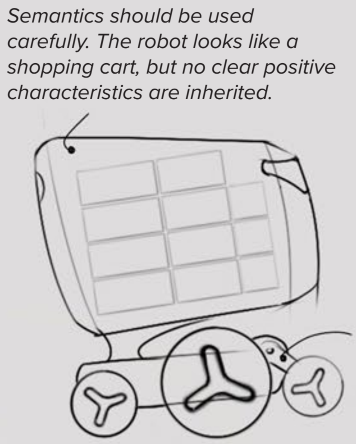
Both optimizing the robots intelligence and gesture communication will be investigated further. Simulations will be made of pedestrian-robot interactions, based on the earlier mentioned social-forces model. The goal is to exploratively find predictable robot behaviors and methods for solving complex scenarios. The gesture communication will be tested during a user experience test in VR, to find out how it influences the interaction and how natural and intuitive it is experienced by pedestrians.

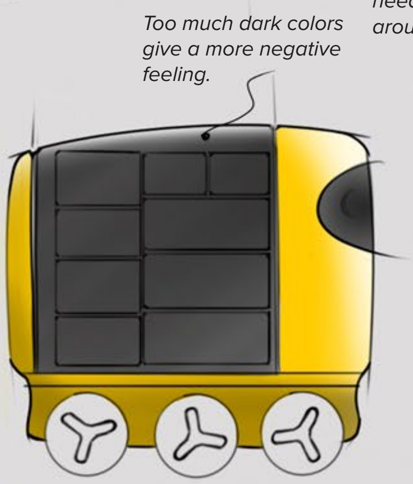
Form considerations

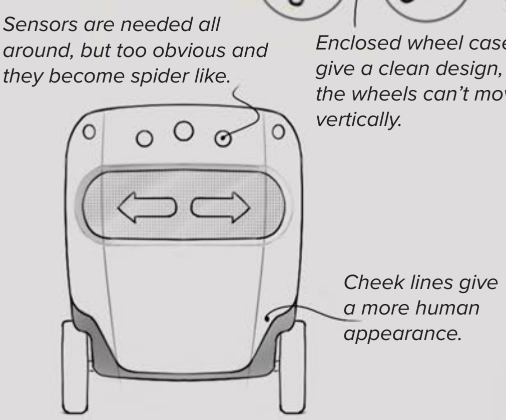


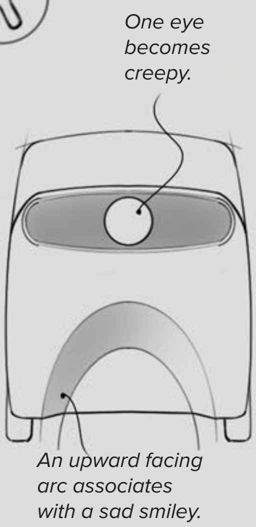


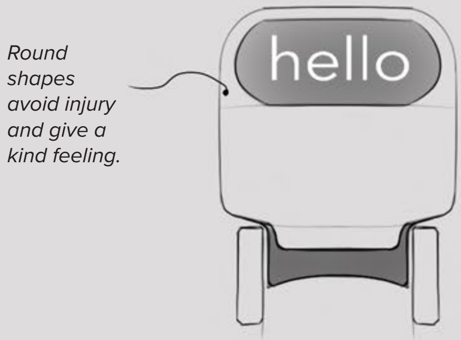


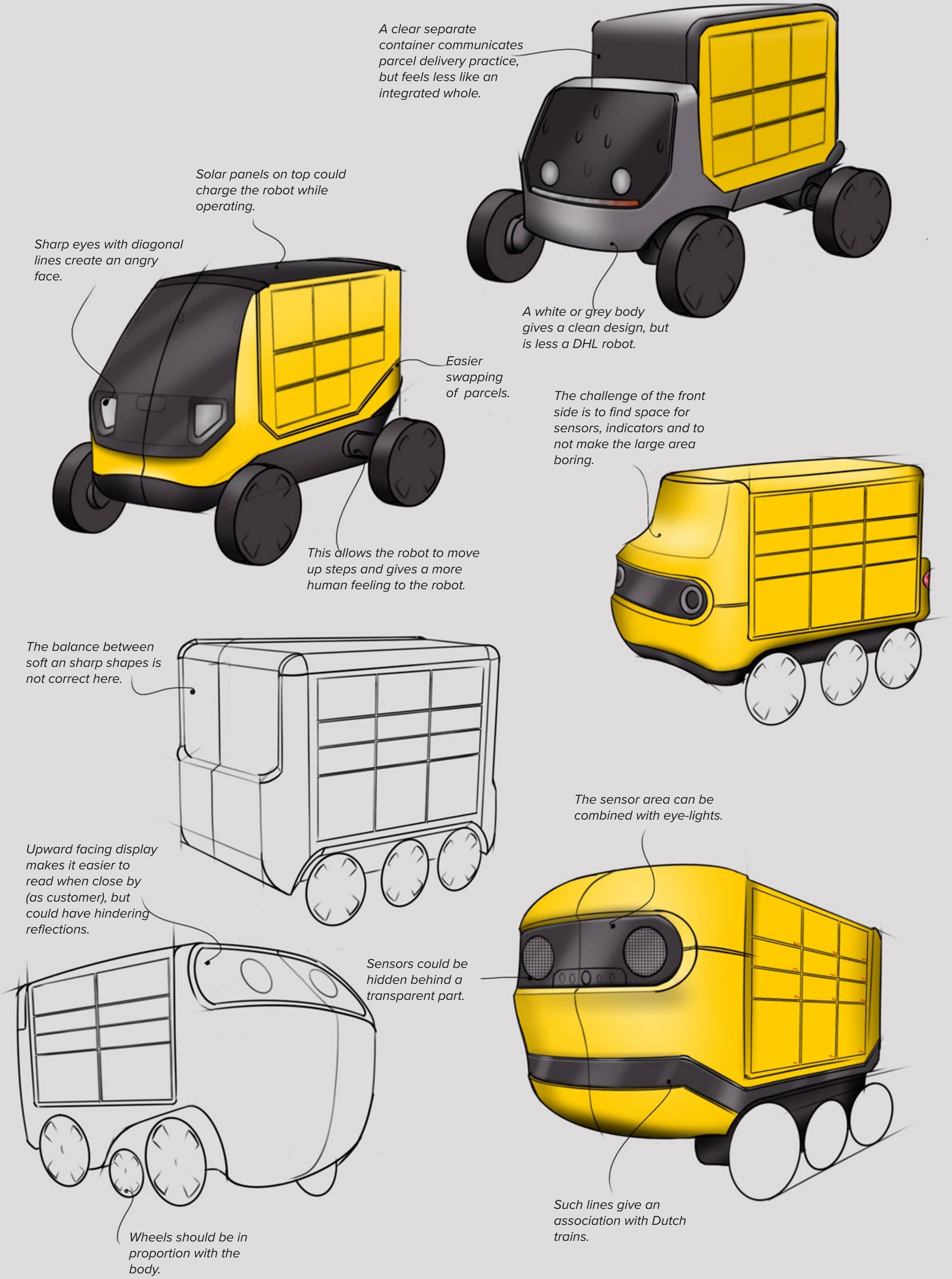











A clear separate container communicates parcel delivery practice, but feels less like an integrated whole.
Solar panels on top could charge the robot while operating.
Sharp eyes with diagonal lines create an angry face.
A white or grey body gives a clean design, but is less a DHL robot.
Easier swapping of parcels.
The challenge of the front side is to find space for sensors, indicators and to not make the large area boring.
This allows the robot to move up steps and gives a more human feeling to the robot.
The balance between soft an sharp shapes is not correct here.
The sensor area can be combined with eye-lights.
Upward facing display makes it easier to read when close by (as customer), but could have hindering reflections.
Sensors could be hidden behind a transparent part.
Such lines give an association with Dutch trains.
Wheels should be in proportion with the body.

Design direction 1

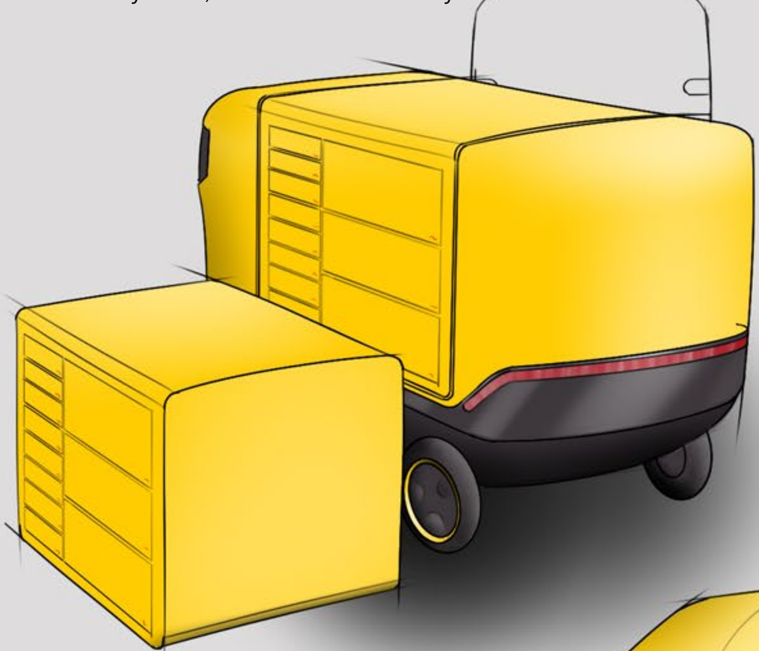
To give the robot a higher level of humanness, the robot has dynamic eyes, which point into the direction that it is going. The display can also be used to interact with customers, or in emergency situations, show instructions or the face of a human teleoperator.

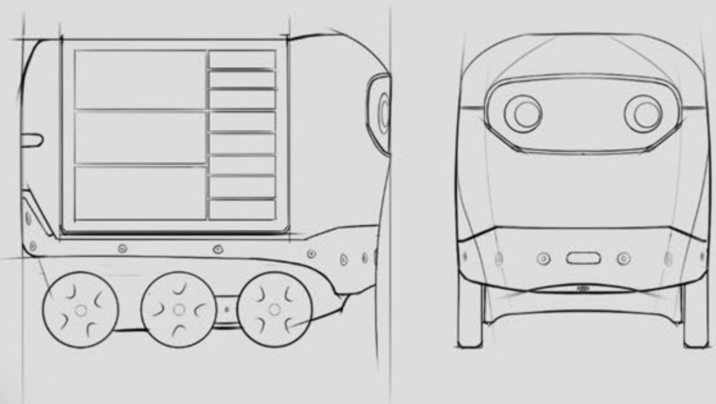
The soft shapes on the front and back of the robot give the robot a slightly more human appearance. This is in balance with some sharper corners to bring more attention to the display and to give a more defined appearance. This balance between soft and defined can also be seen in the color and material choice. A more softer and lighter mate yellow, combined with shiny black elements.

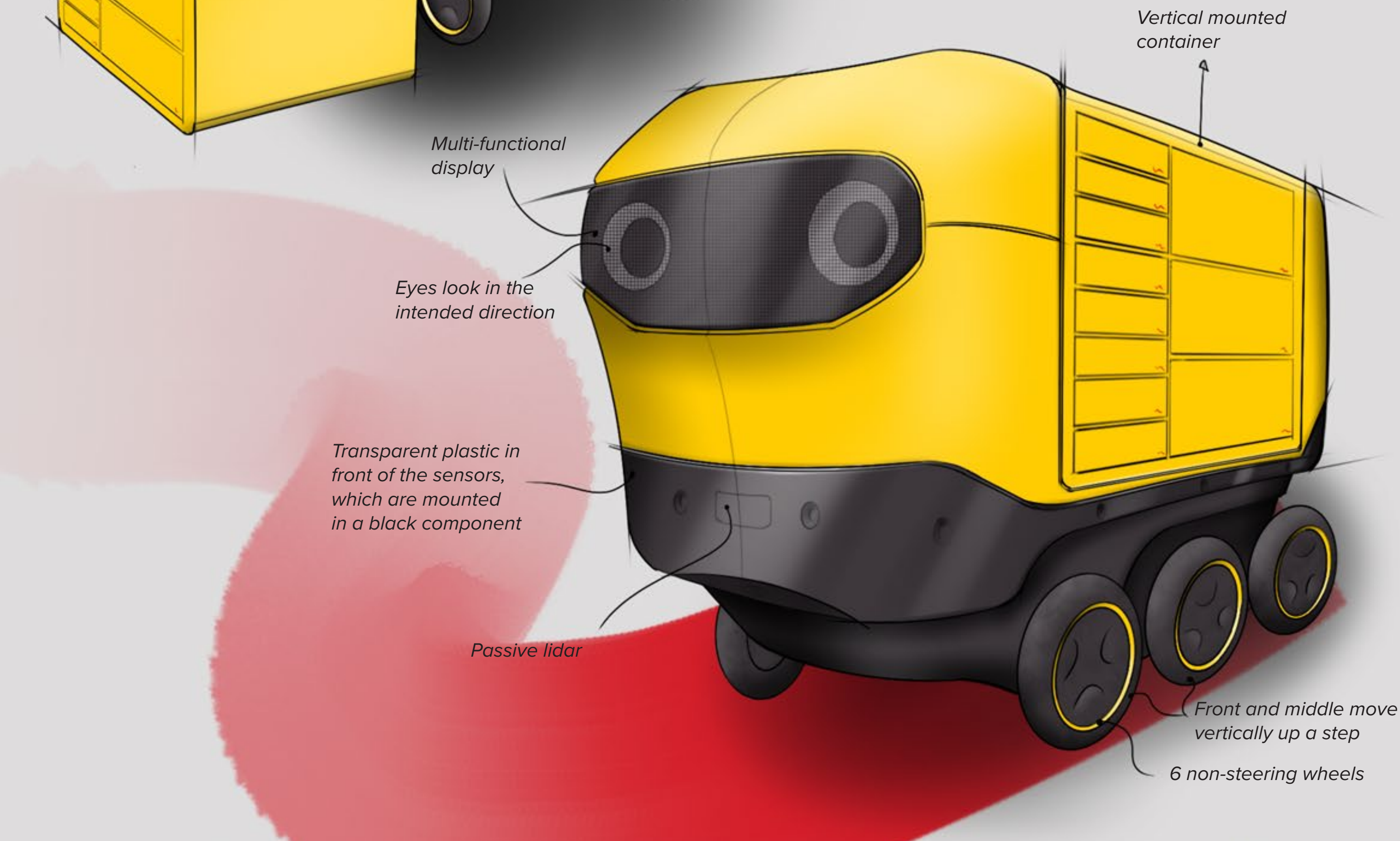
By making the lower part of the robot black, the perceived point of mass is positioned higher, giving the robot a slightly more human appearance.

The container of the robot can be mounted vertically onto the robot.

The six wheels give the robot a steady pose. On either side, the front and middle wheel are connected, with an axis of rotation in the middle. This setup, which comes from the Mars Rover, allows it to move up a small elevation.







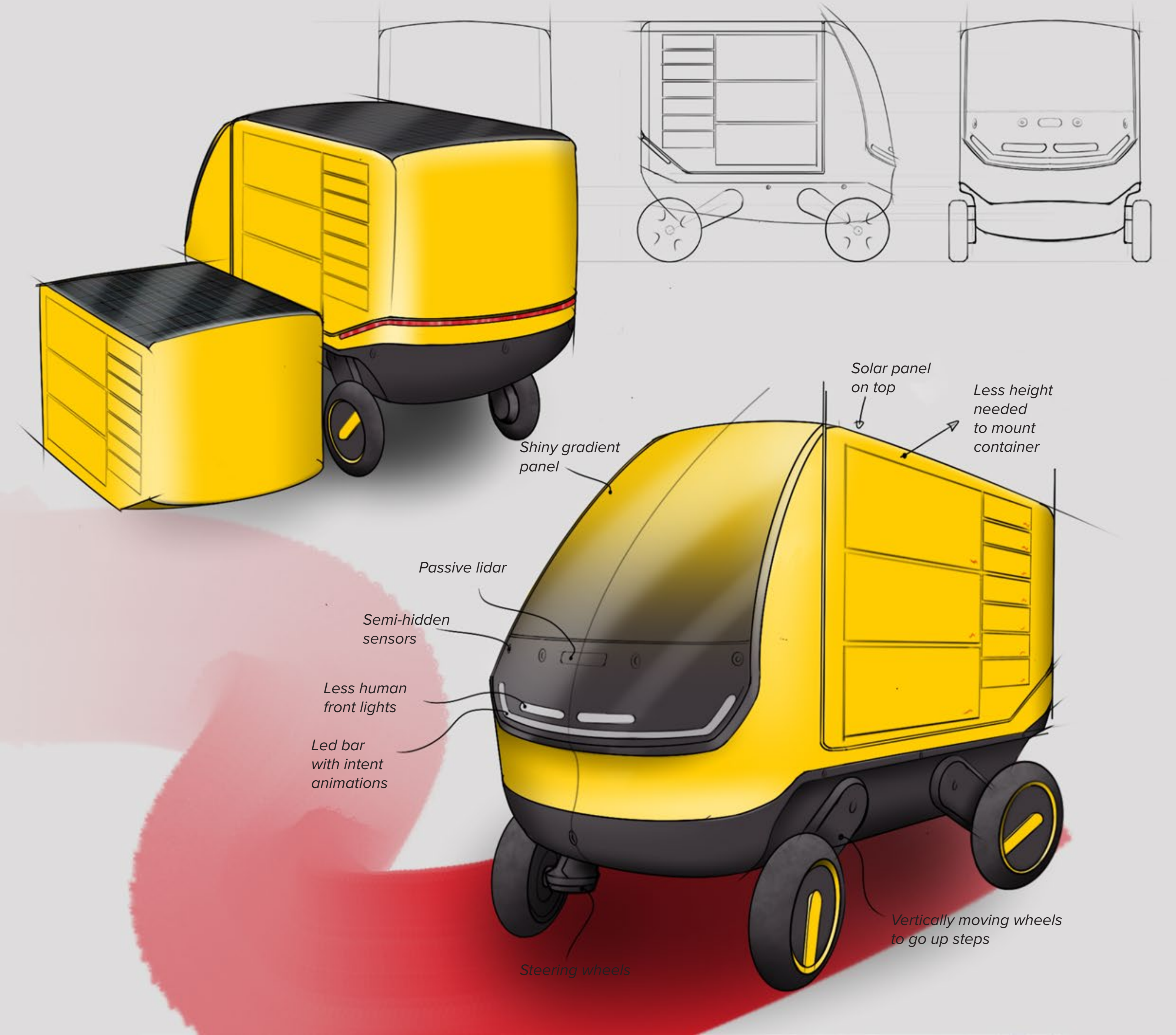
Design direction 2

This robot is a slightly more machine looking robot. The lights on the front give an indication of human eyes, which is also used in cars. The large led bar extends upwards to give the robot a positive “smile”. Also the lower side of the yellow part curves into the positive direction. In the lower section of the glossy front part, the sensors are positioned semi-hidden. Extending upward a gradient transitions between black and yellow. This merges the black sensor area better together with the rest of the yellow body and therefore acts less dominant.

The robot uses linear animations on its led bar to communicate intent. This is done on the front side and the back side.

The container can be mounted from above, and less space is needed than direction 1, since the back side of the robot is mostly open.

The robot has 4 wheels, with the front wheels turning, which can be perceived by a pedestrian as an intent indicator of turning. All wheels can move vertically, to go up a step, but it also gives the robot a more useful appearance and gives a slight feeling of humanness.



Design direction 3

Direction 3 is the most machine-like robot. The front lights are positioned far apart and the shape is very functionally efficient. It is recognizable, but could also be perceived as a little old fashioned or boring.

The container is the easiest to swap of the three directions, since only a little vertical upward movement is needed. This setup requires all of the important components to be in the bottom side of the robot, which makes this visually heavier, steadier on the ground and it is perceived as less dynamic in its movements.

The front two wheels can steer, which indicates that it is about to turn or that it is turning. There are no intent indicators in the lights.

Design direction choice

Direction 2 was chosen for further testing and development. This direction seems the most promising, when looking at the insights gained in the research phase and is the most applicable to test a variety of intent indicators.

This robot has the right amount of humanness. Its facial elements are positioned quite low, which makes it less human and less prominent. The robot has a higher perceived point of mass, due to the wheels that are connected to a rotating bar. This makes it a little higher from the ground and therefore gives a more dynamic feeling. However, not too dynamic, since the wheel-basis is large enough to give a sense of predictability. This setup increases the perceived usefulness, since the robot is able to handle all sorts of surfaces and steps. The robot is able to drive slightly diagonally up a step, by independently moving the wheels up and down.

The front side is made of glossy plastic, which creates a good contrast with the mate yellow. This gives it a modern feel and can be associated with a lot of modern tram and train designs. The gradient on the front gives the feeling that the black area for sensors and indicators fits well together with the rest of the body. It decreases the dominance of the black area.

This robot is also the ideal robot to test different intent indicators. A more machine like setup, like currently visualized in direction 2, works well. But also dynamic eyes, such as with direction 1, can be implemented.

Evaluating the intent indicators

To communicate what the robot is about to do, two intent indicators were designed. Their effectiveness is tested in user experience tests in VR. This section describes the goals of the test and the insights gained. The test also focused on gesture communication, which will be described in the next chapter. See appendix E for the full description of the test.

Goals of the test

The goal of the test is to find out if the animations are sufficiently visible, are understood by pedestrians and help with having efficient and comfortable pedestrian-robot interactions. Furthermore, there might be other aspects of the robot or the environment that help pedestrians with choosing how to cross the robot.

The two intent indicators are compared with a robot without any dedicated indicator. In figure 37, the robot in the middle has a led bar which has a rather mechanical way of interacting intent, by using an orange blink. The orange light moves from the middle to the side to emphasize the blink, like luxurious cars do. The blink is repeated as long as the robot is turning. The eyes of the right robot look in the direction that it will go to. The animation is played once, but it keeps on looking, till it has finished the turn.

Figure 37. Robots indicating turning.

The same robots are visualized in figure 38 while performing a braking indication. The middle robot has the led bar which declines towards the middle. This represents the decrease in velocity. The one on the right closes its eyes to indicate that it is “resting”. The animations of the led bar and the eyes are played once.

Figure 38. Robots indicating stopping.

Research questions

- For what robot cues or characteristics do pedestrians look in order for them to have a comfortable crossing with the robot?
- What is the influence of intent indicators on the crossing interaction between pedestrian and delivery robot?
- How well are the two designed intent indicators perceived and understood?

Test setup

During the test, the participants are asked to walk efficiently and comfortably towards the bus station in the distance, while avoiding the obstacles and robot. See figure 39, for the virtual environment setup. The participant starts walking from the green plane on the ground, at the moment that the cubic obstacle turns green. He will then chose to go left or right from the obstacle, potentially based on the behavior of the robot.

The participants walk physically for about 3,5 meters, which was the available space in the test setup. This means that they stopped next to the block.

There were in total 9 scenarios, of which 6 where focused on the intent indicators. This comes down to the three variations of indicating, both for stopping as for turning right around the block. After each scenario, the participants were asked some questions about their experience (see appendix E).

Figure 39. Virtual test environment.

Results

See figure 40, for the average perceived comfort per scenario, the visibility of the indicators and how well the robot communicated its intentions. The led bar is a good intent indicator, which is both well visible and well understood. This improves the experienced comfort. One scenario, which is the robot with the eyes that stops, has a very high score for comfort. This is not because of the indicator, but because a fault in the VR model made the robot hold strongly left. This resulted in a very easy decision by the participants to take the other side. See appendix E for the full set of results.

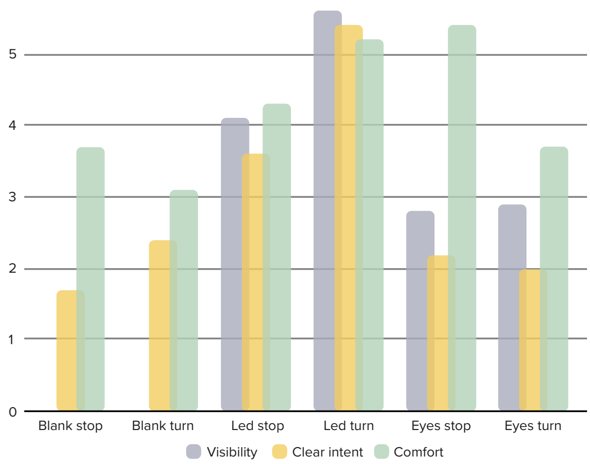


Figure 40. Average score per scenario.

Conclusion

Some strong insights were gained by the VR user experience test. Implementing an intent indicator on the robot has a positive effect on the experienced comfort by the pedestrian, for scenarios in which it is not possible to see what the robot is going to do in another way. This is only true if the indicator is both highly visible and understandable. The turning and braking indicator on the robot with the led bar is both better visible and more understandable than a robot with eyes which look into the driving direction. The led bar's orange blinking light has a strong association with car directional lights and is therefore recognized without doubt by the pedestrians. The led bar also has a positive effect on the "kindness" of the robot, because the "mouth" makes the robot more human.

Intent indicators should not be utilized for every movement the robot makes. If the robot is acting in a busy situation, it should first of all be solved by taking a path which solves the situation best and this path should be set in early, so pedestrians can adapt their path early on. This is very similar to how pedestrians interact with other pedestrians and therefore uses the same mental model. The reason why intent indicators should be used selectively is that otherwise pedestrians start to depend on them to have a comfortable interaction. Just like in the test, where the pedestrians were waiting for the robot to indicate something, before they comfortably could make a decision. If the indication comes late, there is a relatively long period of doubt and even slowing down by the pedestrian. The indicators should only be used in situations in which the robot will take a sharp turn, needs to go around the corner, in dangerous situations or when the robot will maneuver itself to a position on the sidewalk where it will wait for a customer. For smaller movements, pedestrians will look at the position of the robot, its direction of movement and cues like turning of the wheels.

Evaluating the gesture communication

The last 3 scenarios of the user experience VR test, were dedicated towards testing the gesture communication. See appendix E for the full description of the test setup.

Goals of the test

The goal of the test is to see if pedestrians experience a positive effect of using gestures, to communicate with the robot, while crossing. Furthermore, it is tested what gestures are experienced as a natural interaction with the robot.

Research questions

- How do posture gestures influence the crossing interaction between pedestrian and delivery robot?
- What posture gestures do pedestrians think will yield good pedestrian-robot interactions that will help them to cross each other comfortably?

Test setup

After performing the other 6 scenarios, which were focused on the intend indicators, the participants were explained that they are able to communicate with the robot about who is going in which direction. They are not explained what specific gesture can be performed, only that it can be a hand gesture, arm gesture or posture gesture. During the scenario the robot will react on the gesture, if it was performed before it had to make a decision. It will go in the opposite direction of where the gesture is pointing to. The robot does not react on stopping gestures. The input for the robot is by a Wizzard of Oz principle and done by a keyboard click.

Results

In figure 41, it can be seen that there were three meanings that the participants had with their gestures. Pointing the robot to where it needs to go and pointing in your walking direction is a similar hand movement, but with opposite meanings. Pointing what the robot should do felt more natural for the participants. In a third of the scenarios, no gestures were used. They were either forgotten or the participant assumed that the position you have and the path you take, should be enough for the robot to understand your intentions. Using no gestures felt the most natural.

GESTURE	# OF TIMES	NATURALNESS
Walking direction	8	3.5
Point robot	9	5.0
Stop robot	3	4.3
No gesture	10	5.9

Figure 41. Types of gestures performed and their naturalness.

Conclusion

When being able to communicate with gestures, participants took more initiative in choosing a side to go to, while hesitating less. In that way, this extra sense of control had a positive effect.

Using gestures to communicate with the robot about who is going to which direction is not seen as a natural interaction. Pedestrians don’t do this in real-life and using interactions, from for instance cycling, are not easily implemented in the sidewalk context. Gestures become very confusing, because different people use similar gestures to communicate different things. If the robot then reacts unexpectedly, it can both become dangerous and irritating for the pedestrian.

It should also be taken into account that in complex and busy situations, a robot might not be able to react on your gestures, since it also needs to take into account other entities in the environment and potential other gestures.

The best solution is to not implement a specific gesture, but to find other ways in which pedestrians can get a feeling of control.

Reconsidering pedestrian-robot interaction

A more considered approach is needed to reach the objectives described in the design goal. Earlier design decisions had some unintended implications for how intuitive the situation is experienced and how much control was felt.

Intuitive interaction

In the design goal it is described that the interaction with the robot should be intuitive. This can be achieved by using interactions that match with the mental models that people already use when interacting with pedestrians or with technology. Using eyes that look in the direction of where the robot is heading, was a new interaction which did not fit with already existing mental models. The blinking directional light performed better and there was an easy association with car blinking lights. The result is an intuitive understanding of the indicator itself. However, the context of cars is way different from that of the sidewalk. Pedestrians fluently move around each other by taking into account the position, direction and speed of pedestrians (hereafter called movement information). A blinking light on a robot is in this context less intuitive. This could be seen in the test by a changing decision making method by the participants. Instead of using the movement information of the robot, they depended heavily on the indicator. Since the indicator is only visible just before the robot is about to do something, it creates longer periods of doubt for the participants, postponed decision making and even failing to make a decision when the robot is not indicating its intentions sufficiently.

The indicator itself is intuitively understood. But it is not intuitive within the flowing dynamics of the sidewalk, where timing is very important and where pedestrians don't want all their attention to be on an indicator. To really have intuitive interactions, the behavior of the robot should correspond more with that of humans. Pedestrians could then use the same mental models they use for interacting with other pedestrians on the sidewalk. Movement information is a continuous cue that gives insight into what another pedestrian or a robot is about to do. This can create very comfortable crossing interactions, as was seen in the VR test with the robot that held strongly to one side and was therefore seen as the most comfortable interaction of all. The robot should maneuver in such a way that it uses its movement information as a clear and timely cue of its intentions.

Feeling of control

Since people have a basic need for control in their life, this should be taken into account in the robot's design. During pedestrian-robot interactions, control can be described as being able to take initiative in a situation and trusting that the robot will adjust to that. In the VR tests, it became clear that intent indicators have a significant negative effect on the control that pedestrians experience. When the robot uses an indicator, it means that it is taking initiative over how the situation is handled and puts the pedestrian in a position in which it needs to react to the robot. There is very little control for the pedestrian in these cases. As a countermeasure, the gesture communication was introduced. This gives pedestrians the same kind of control as the robot has, which makes them of equal importance. Apart from gesture communication being a confusing way of interacting, it also creates a "first come, first serve" situation. It will be a constant struggle between the pedestrian and the robot trying to take control over the environment, which is a very active activity and needs quite some attention from pedestrians.

From the future vision came the criteria that the interaction of taking control should feel like a "smooth understanding". Both intent indicators and gesture communication are not fitting with this description. To achieve this "smooth understanding", it is needed to take an approach that is more similar to how pedestrians interact with other pedestrians. As described above, this can be done by using movement information. This information is used by pedestrians to determine their own path, as is described in the chapter about the social forces model. The model consists of mathematical equations that simulate how pedestrians react on other entities in their environment. On the core of its maneuvering logic, the robot could use the same model. The goal is that pedestrians unconsciously understand that the robot reacts similar to pedestrians and therefore use the same kind of interaction. They don't need to adapt much to the robot and it takes less effort to learn a new way of interacting. The next chapter about robot behavior-simulations, goes into implementing the social forces model into the robot's behavior.

Functional efficient design
In the VR tests it also became clear that the robot’s body cues are an underrated way of communicating intentions. Especially in scenarios where the participants were not distracted by the intent indicators, they started to notice the movement of the wheels more. In the design of the robot and in its behavior, there could be more emphasis on these features.

Another example could be the suspension of the robot, which allows it to control the height of each corner of the body individually. This can be used to emphasize natural movements that wheeled vehicles have when they turn or accelerate. When braking, the momentum of the body is converted in a slight swing to the front, pointing the nose of the robot down. The opposite happens when accelerating. When turning, the body swings outward a bit. The robot could emphasize this behavior, or start the movement slightly earlier than normal. This communicates more clearly what the robot is doing and what it is about to do. An advantage of this approach is that it is visible, without specifically focusing on the robot or on its indicators. However, it is a subtle cue, which will not be visible to anyone and therefore only has a supporting function on top of other cues.

Robot behavior simulations

As described in the research phase, the movement of pedestrians can be explained by the social forces model. A pedestrian experiences an attractive force from their final destination and repelling forces from other pedestrians and obstacles. The sum of the forces determines their walking direction and speed. In this section, this social forces model is translated into an Unreal Engine 4 model. In this way, complex pedestrian scenarios can be simulated in a virtual environment as well as the behavior of the robot.

Goals of the simulations

- Test the feasibility of using the social forces model in a controlled simulation environment.
- Gain insights into the parameters needed to create a desired robot behavior.
- Validate if the social forces model is able to generate human behavior into the robot that feels familiar and predictable.
- Determine how much initiative the robot should take or how reserved it should be.
- Find design limitations and possibilities of using the social forces model.

Model setup

First the social forces model was used to build the behavior of the pedestrians. This code is implemented into the robot and adjusted to work with the robot specific characteristics. Differences between the two versions are that the robot has a minimum steering radius and moves based on vehicle dynamics, which requires a wheel turning and throttle input. See appendix F for an explanation about the underlying code for the "Pedestrian Pawns" and the "Robot Pawn".

In figure 42, a simplified overview can be seen of the Robot Pawn blueprint. The main principle of the blueprint is that the robot senses all entities in a radius of 5,5 meter and calculates the force "experienced" from that entity. To calculate this force, the distance and angle towards the pedestrian is put into a curve, which outputs the importance of this pedestrian. For instance, pedestrians straight in front and at close range, have a higher importance than entities on the side and far away. The vector in the opposite direction from the sensed pedestrian is normalized and multiplied with the factors of importance. The resulting vector is offset by 30 degrees. This makes sure that there is more sideways component to the force and that the robot moves easier to the side, instead of decelerating. There can be more than one pedestrian in the sensed environment, so all these forces are add up to create a total pedestrian force. The sum of attraction and repulsion forces determines the final direction and velocity of the robot.

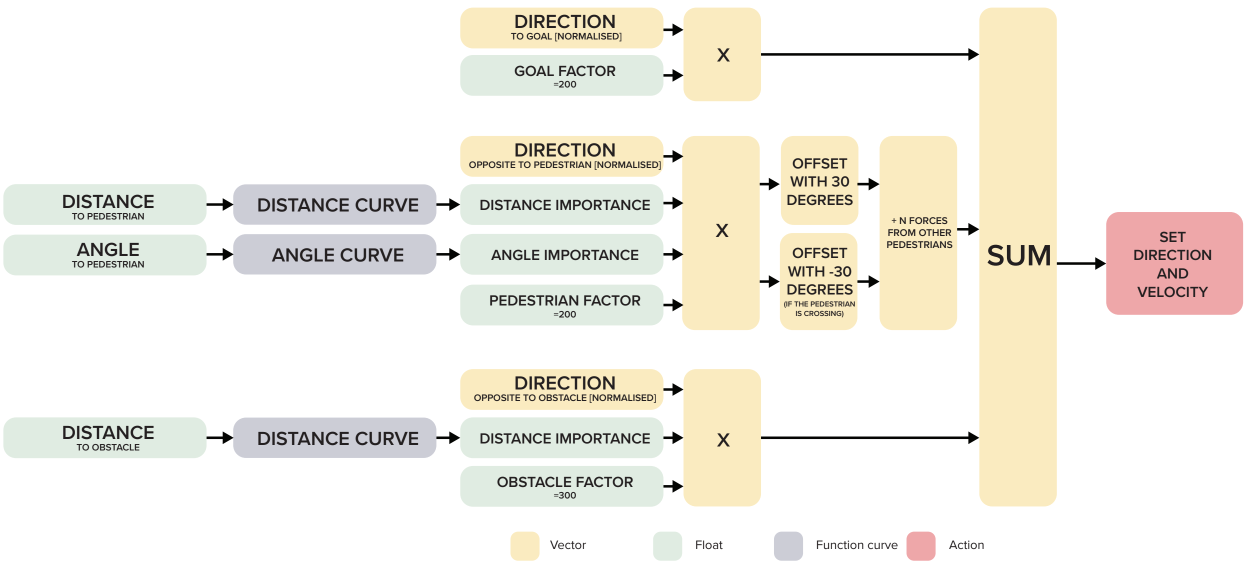


Figure 42. Simplified representation of the robot pawn blueprint.

Approach

An experimental approach was taken to find well functioning parameters for the pedestrians and the robot. For these simulations, the focus was not on replicating the social forces model from literature identically. An interpretation of the model was implemented and formed the basis for further iterations. Goal of the changes was to make the robot operate based on the movements of it's wheels and to find good parameters that resulted in desired behavior.

Results

Angular offset of repulsion forces
In the original social forces literature, the repulsion forces from pedestrians were directed in the direct opposite direction of that pedestrian. However, this results in a sum force which is not affecting the sideways movement much and results mostly in deceleration. By offsetting the repulsion force with 30 degrees, the robot is more inclined to steer to the side and there is less speed reduction.

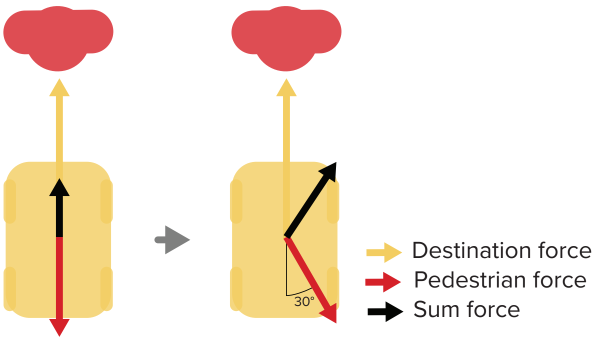


Figure 43. Angular offset of repulsion forces.

Distance importance curve
The closer a pedestrian gets to the robot, the stronger the robot should react by turning away or stopping. However, this is not a linear relation. In figure 44 the relation between distance and importance of the force can be seen. The plateau up till 60 centimeters and with importance of 1.9, is the area which for safety reasons pedestrians may not enter. At 5,5 meters, the curve smoothly starts, so the repulsion force gradually builds up and the robot reacts smoothly. Increasing the importance at large distance is a tempting method to make the robot react very early to pedestrians. This works well when encountering one pedestrian. The robot will deviate its path quite early. However, on crowded sidewalks, this results in the robot experiencing significantly high forces, from all entities within the sensed range. The sum of the forces, is too large, which makes the robot stop and stand still till all pedestrians have passed. This already happened with slight increases of importance at 5 meters.

Directional importance curve for opposing pedestrians
The area straight in front of the robot has the highest importance, since the chance of a confrontation or collisions is the highest. The needed steering radius of the robot has the result that the robot needs more space in front, to get out of the way of a pedestrian. The importance factor until 20 degrees is therefore relatively high. Behind the robot, the importance factor is only 0.2, since the pedestrian has already passed and is walking further away from the robot. The middle section of the curve is also relatively important. If the force from pedestrians between roughly 45 degrees and 135 degrees is too high, the robot will keep a very safe distance when

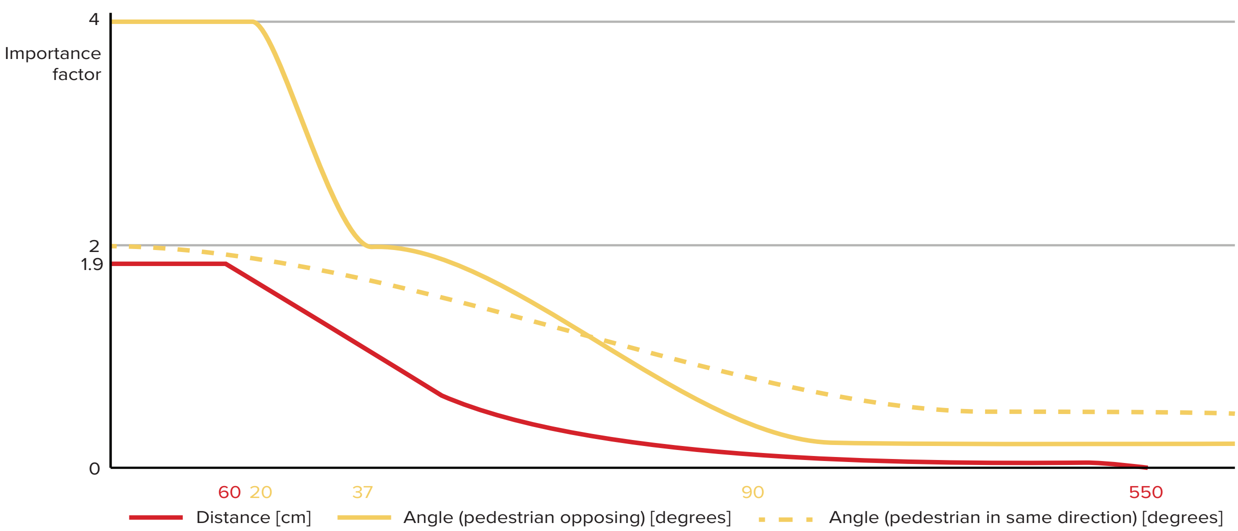


Figure 44. Three curves determining the importance factor for the distance and the angle.

passing pedestrians. This will feel comfortable for that pedestrian, but with a crowded sidewalk, the robot will have trouble finding a path in which the repulsion forces will not bring him to a stop. Another negative effect is that it will move more dynamically over the sidewalk and become less predictable.

Directional importance curve for pedestrians in the same direction.
Pedestrians in the same walking direction are less of a threat to confrontations and collisions. Straight in front the importance factor is therefore 2. This is high enough so the robot will not approach too closely, but low enough, so it can follow a pedestrian walking in the same direction. Pedestrians that are walking behind the robot could run into the robot if it slows down too abruptly. Therefore, an importance factor of 0,5 still has a little effect on forces in the robot's forward direction. This only works if the robot is driving very slowly. When it reached its maximum speed, it will not go faster.

Adjusting behavior for crossing pedestrians
Due to the robot having wheels with a minimum steering angle, the reaction to the sum force is different than a pedestrian, which can pivot around its axis. Without any adaptations to the model, this results in unwanted behavior, when a pedestrian is crossing the robot. In figure 45, it can be seen that if a pedestrian is on the right side of the robot and moving towards the left side, the robot will move left, cutting of the crossing pedestrian. This happens because the robot only looked at the position of the pedestrian and not to its walking direction. An addition to the model is made, in which the standard angular offset of 30 degrees is turned into the opposite direction. This results in the robot turning to the other side and slowing down slightly more.

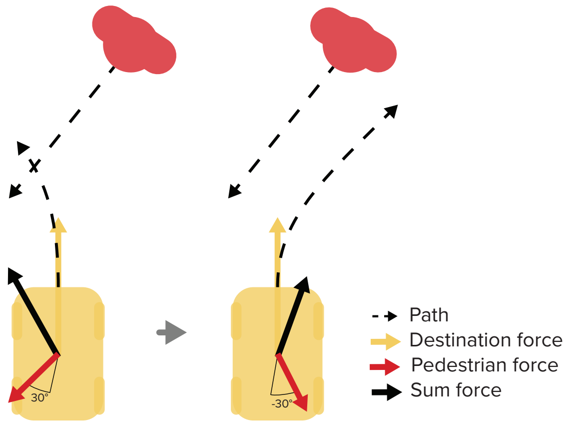


Figure 45. Crossing pedestrians negative offset.

Simulated behavior
The resulting behavior looks natural. It keeps a safe distance from pedestrians and reacts significantly early to opposing pedestrians. During optimization a balance was found between the robot's behavior in a group and minimizing the force on specific pedestrians. It was found that this balance can be hard to accomplish. Adjusting a parameter slightly to decrease the experienced force by a pedestrian, might reduce to robot's functioning in a crowd significantly.

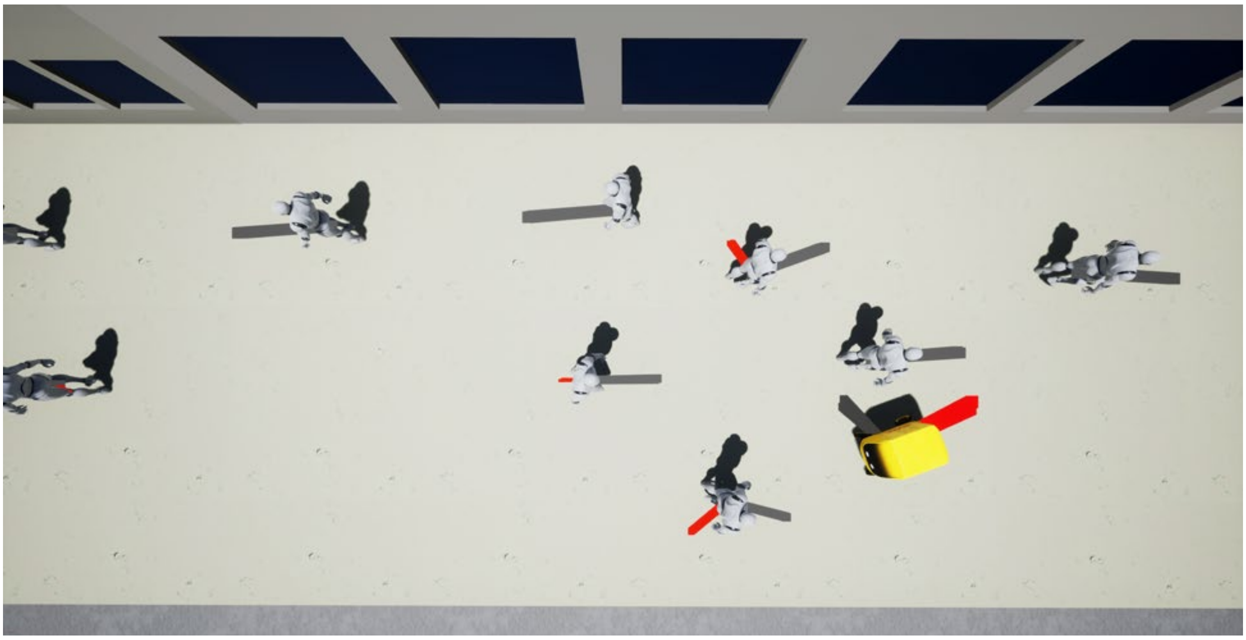


Figure 46. Length of the red lines are the total of repulsion forces, the grey lines are the sum force, including goal force.

Discussion

Due to the potential research opportunities for using the social forces model, there is an extended discussion in appendix F.

The general point of discussion, is that the implementation of the model was done in such a way that it was manageable to create results within the available time. Therefore, an interpretation was done on the overall principle of social forces literature and more specific the one from Helbing and Molnar (Helbing & Molnar, 1998). Mathematical formulas were represented with curves, which allowed for fast iterations. More research should be done in alternative social force models and how to implement them more precisely.

A larger variety of scenarios should be tested. The focus of these simulations was on optimizing the robot's behavior on a sidewalk where all pedestrians have a destination which is at the end of the sidewalk. Therefore, no optimization was done on pedestrians walking perpendicular to the robot. Other scenarios which are not taken into account with these simulations are:

- Different pedestrian personalities that experience larger or smaller repulsion forces.
- Robot behavior when overtaking slower walking pedestrians.
- Pedestrians that unexpectedly change their goal destination.
- Very narrow sidewalks
- Very busy sidewalks.

It should be taken into account that the simulations only partly represent real-life scenarios. Pedestrians might react differently to the robot, since it is an unknown device. The variety of reactions will be large in practice. Elderly, might be more cautious towards the robot. Or children, might jump in front of the robot and start playing with it.

Conclusion

The result is a robot behavior which is optimized based on its visual applicability to the different situations and by decreasing the forces experienced by one pedestrian. The robot moves safely in a natural and predictable way, in scenarios for which it is designed. The research showed that there are however quite some scenarios in which the current parameters don't function properly. This could be assigned to the robot having a steering radius instead of a pivoting movement. The effect of this difference should be researched more for a wide variety of scenarios.

A large benefit of the model is that the social forces model is inherently connected to human behavior. Current delivery robots might rely more on keeping a straight path and expect pedestrians to adapt. It is then more unexpected when the robot suddenly changes its path. Its turning behavior is not inherently human, which makes them feel less familiar. The social forces model has the potential to solve this. Although pedestrians will not be aware of this difference in programming, after a few encounters with the robot, they will get used to it's behavior and will feel in control on their sidewalks.

Implementing a social forces model into a physical robot that performs well in all scenarios, will be a challenging task. However, this is just as much the case for other ways of programming. The benefit of applying the social forces model is that it has the potential to solve most of the scenarios with the same piece of code. Furthermore, there are additional potentials. With only limited input, the model can be used to make short term predictions of what pedestrians are going to do, or how crowds will behave. The model also provides the opportunity to optimize interactions based

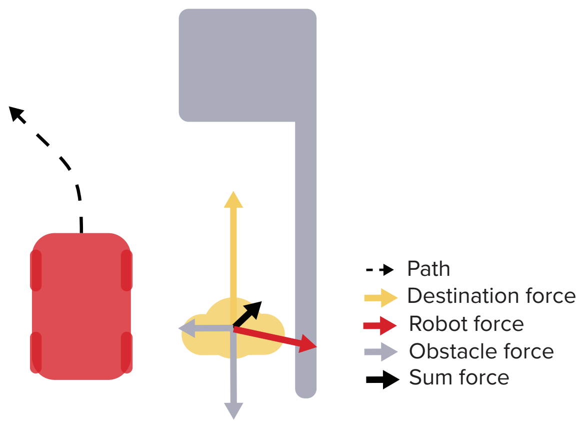


Figure 47. Decreasing repulsion forces experienced by pedestrians.

on quantitative data. Interactions will be more comfortable for pedestrians if the social forces they experience are lower. A machine learning algorithm could be implemented on top of the simulations, to find optimal parameters that achieve maximum comfort. Also in real-life the robot could calculate the forces that pedestrians experience. In figure 47 for instance, a pedestrian experiences high repulsion forces from obstacles and the robot. After having sensed this increase in discomfort, the robot could make space for that pedestrian, while taking into account the extra forces that it might generate on other pedestrians.

Above some opportunities are explained to use the social forces model in a non-standard way, to improve interactions on the sidewalk. This means that the robot should be able to take initiative in interactions, if it knows that it has found the optimal way of increasing everyone's comfort. This initiative can be taken by communicating the intended path earlier than pedestrians do. Figure 48 describes the use of initiative and it's potential effect on the interaction.

Based on this research, the reaction time should be very similar to that of pedestrians, during regular interactions. This creates an equal importance on the sidewalk. There is a possibility to make the robot react slightly later than pedestrians. In this situation, the robot is reactive to pedestrians and has therefore limited opportunity to take into account the effect of its future path. The positive effect of pedestrian initiative is that the feeling of control by that pedestrian might grow, since he has the power to decide how the interaction will go. The last possibility is to make the robot react earlier than pedestrians. This could be implemented if the robot has sensed that this decision will increase the comfort for some pedestrians and doesn't endanger the comfort of others. The result of this early initiative by the robot is that all pedestrians could benefit from better interactions, because of the robot's analysis.

In general, how early the robot reacts to opposing pedestrians is one of the most important parts of the robot's behavior. Pedestrians have the habit to communicate their intended direction very early. Especially on empty sidewalks, this decision, or negotiation with another pedestrian, could already be at 10 meters apart. At those distances, the social forces model will not function. An adaptation to the model should be made, like a very strong effect on long distances, when there are very few pedestrians. Or the robot could always have the bias to stay to the right.

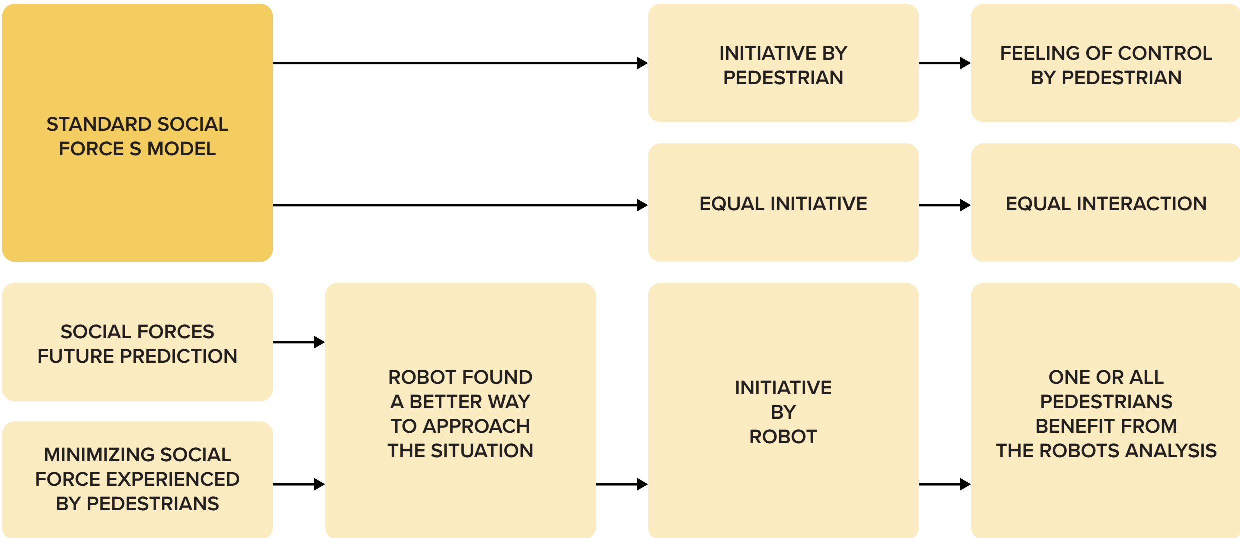


Figure 48. The role of taking initiative in creating optimal scenarios.

Evaluating social forces behavior

It was assumed that a more human-like maneuvering would make the robot more predictable. To test if this is true, another user experience test in virtual reality is performed, where participants take part in the social forces simulation.

Goal of the test

The goal of the test is to see how pedestrians react to a robot which moves based on social forces. Does it make the robot more predictable and does it give a feeling of safeness? It might be that a robot which moves in a straight line is more preferred than a robot which mingles in with the flow of pedestrians. Evaluating the social forces behavior is part of a larger user test, which also benchmarks the appearance and tests the special indicators. See the full documentation of the test in appendix G.

Research questions

- How predictable is the behavior when people first encounter the robot?
- What robot behavior makes people feel the safest?

Test setup

Participants' perception on three different robot behaviors is tested. In the first three scenarios the participant is standing and observing in VR on a sidewalk, within the simulations. After each scenario questions were asked about how the behavior was experienced.

- Scenario 1: The robot brakes based on the designed social forces behavior, but keeps a straight line. This is the most machine-like robot.
- Scenario 2: The current design of the behavior, with a robot which participates in the flow if pedestrians, but is not too dynamic and unpredictable.
- Scenario 3: A more dynamic version of the robot which steers much also at high speeds.
- Scenario 5: The current design of the behavior, similar to scenario 2, is used, but participants can walk around for a few meters in the environment. The robot reacts on the participant.

Results

How the robots' behavior was perceived by the pedestrians can be seen in figure 49. The final behavior design (scenario 2) scored the highest on experienced feeling of safety. The more dynamic robot from scenario 3 scores slightly lower, followed by the static robot. However, this does not mean that the designed behavior is also the most predictable. The static robot is seen as most predictable, followed by the design and thereafter the dynamic robot. The designed robot behavior adapts the most to pedestrians and the static robot the least.

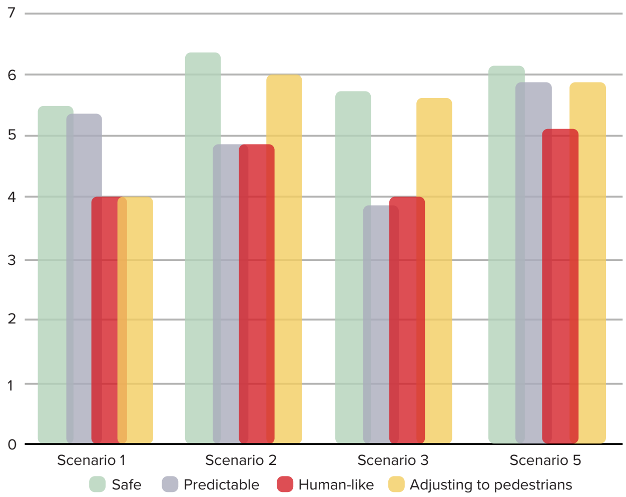


Figure 49. Perception of the different robot behaviors on a Likert scale from 1 till 7.

Discussion

The participants had to state how human-like they experienced the movement of the different robots. This was seen as a hard to answer question. They see the robot as a machine and expect it to move like it. Participants don't know with what human behavior they should compare it with. Most answers might have referenced to the behavior of the eyes and not to the maneuvering of the robot. Therefore, this question could better be left out of analysis.

The participants had to indicate how safe they felt throughout the scenario. This might have been influenced by the simulated pedestrians walking around. The basic Unreal Engine 4 mannequin was used, which is a broad shouldered figure with an aggressive movement pattern.

It was decided beforehand that the participants should have an observing function in the first three scenarios. This makes the test more controlled, since the decision of the participant will not influence the scenario and therefore the test results. The results of the scenarios can now be better compared with each other. However, the feeling of actually participating in the environment is lost, which gives a feeling of safeness.

In scenario 5 the participants were able to walk around, this changes the way of participating and can therefore not be compared well with the other scenarios. Another reason is that there is a learning effect visible. The robot is now, for instance, seen as more predictable than with scenario 2. The participants did already get used to the behavior of the robot.

Conclusion

How predictable is the behavior when people first encounter the robot?
The designed behavior of the robot is seen as less predictable than a robot which is very static in its movements. This can be explained by the expectations that people might have of robots. Robots often move more mechanical. At first encounter it doesn't meet this expectation and is therefore seen as less predictable.

People will assign emotions to the robot's behavior. The dynamic robot in scenario 3 was seen as insecure, since its movements were very shaky and the robot didn't knew what to do. The designed behavior, from scenario 2, is not seen in that way.

If the robot becomes more predictable over time, should be researched further. In the last scenario, which had the same robot behavior as the earlier tested scenario 2, the participants experienced the robot as significantly more predictable than scenario 2 and even the static robot of scenario 1. This learning effect could be similar in real-life in which pedestrians learn that the robot is actively reacting on its surroundings in a consistent manner.

What robot behavior makes people feel the safest?
The designed robot behavior was seen as more safe than the static robot and the dynamic robot. In general, all robots scored high on safety. This result is a good indicator that it has the potential to also be perceived as safe in real-life.

Other insights
In this test it became clear that the social forces model could be optimized further. The robot was adapting significantly to the pedestrians. Due to some parameters, including the offset angle of 30 degrees, compared to the pedestrians offset angle of 15 degrees, the robot deviated more than the pedestrians. The maneuvering of the robot might be more predictable if it is slightly less subordinate and a little more keeping a straight line. This would result in a more equal interaction between robot and pedestrian.

Figure 50. Scenario 2, in which the robot steers away from the pedestrian and the participant.

Form detailing

The robot was redesigned based on the insights gained in the first VR user tests. In this section design choices are motivated.

General
The approach with the detailing was to:

- Make the robot slightly kinder than the version used in the VR tests.
- Optimize the surfaces to create a cleaner look.
- Increase the perceived usefulness and ease of use.
- Better integrate the intent indicators.
- Create desired facial-elements to improve the trust in pedestrians.

Overall shape
The overall shape is coming mainly from the robot that was designed for the VR tests. It was perceived as kind by the participants and the size was fine. Small improvements are made to the surfaces, making them more smooth and defined.

The yellow chin of the robot is made thinner and slightly more withdrawn on the lower part, so the display is visually coming forward more, drawing attention to it.

Display
Using two elements on the front, that are perceived as eyes, make the robot overall kinder and therefore more preferred than none of these facial elements. The “eyes” will not serve as an intent indicator, but they are used for creating trust. The eyes are on a display and are dynamic. They mimic that the robot is looking around in the environment and is sensing the presence of pedestrians. Pedestrians feel that the robot is aware of its surroundings and taking care of everyone’s safety.

The challenge of the eyes is to get the right amount of humanness. The eyes are on a screen which has large visible pixels. This makes it slightly more mechanical looking and creates a positive association with robots like EVE from Wall-E. The eyes are a solid shape, to make them less human-like. Their squircle shape is in between the human round shape and a mechanical rectangle. They are slightly wider than high. Making them more squire would make the robot look too surprised and active. Making them flatter, would give the impression that he is sleepy or not paying attention.

Led bars

On the front, there is a led bar, in between the yellow top part and dark bottom part. In the design used in the VR test, it was positioned just below the eyes, which gave it a weird grimace. It has now a more natural position. It will be perceived as a mouth, due to its extended shape and curve upward. This gives the robot a positive smiling look. The led bar is kept thin, to not draw too much attention on it and to not overdo the resemblance with a mouth. It can indicate the intended direction with an orange blinker in specific situations. In all other situations, it is used as front lighting.

On the back side, there is a led bar, which is used as tail light. It is used as a design element, to make the back more interesting to look at. It is in specific situations used to blink with an orange light into the direction that it is intending to go to.

There are two more led strips (see the next page) positioned on the bottom, above the wheels. This improves the visibility of the wheels at night and makes the robot better visible in general. The light will turn red when the robot is going to stop.

Wheels
The wheels are an important cue that the robot is making a turn. Therefore, the yellow stripe is enlarged, making any changes in the angle of the wheel better visible, when approaching from the front. They are slightly chamfered inward, so the surface is facing you and therefore less reflective.

The rims now have five elements instead of three. An uneven amount of elements is used in more sportive cars, compared to more boring rims with an even amount of elements. Five elements draw less attention than three, so the attention can be used on other things, like the interaction itself.

Container
The lockers on the containers are enlarged in the vertical direction, to handle more sizes of parcels and to increase the perceived usefulness. In the horizontal direction, there is kept enough space for a sliding mechanism.

The container is more visually separated from the robot, by chamfering the edges of the robot inward on some sides. This creates an evolutionary semantic with vehicles from the logistics industry, that have the same kind of separation.

Back
The back is flush with the container and therefore slimmer than the front of the robot. This makes the back less bulky. The wider area on the side is extending to the back and wrapping around the red light bar, which makes the back more defined and less boring.

To house some camera modules in the back, a transparent part is positioned below the led bar. This makes the sensors less visible and keeps them clean.


DHL


DHL


DHL


VR ZONE
VR ZONE
DISCOVER • EXPERIENCE • BUILD
DHL

Evaluating the redesign and robot cues

During the second user experience test in virtual reality, the perception of the final visual design was evaluated, as well as the effectiveness of the supportive robot cues. This section describes the insights gained in that test. For the full description of the test see appendix G.

Goal of the test

The effectiveness of the special indicators is tested, namely the blinking light on the front, the pivoting of the body and the lights on the bottom. The second part of the test is to validate if the appearance of the robot is having the intended effect on pedestrians, a benchmark test is done to see how acceptable it is compared to other delivery robots.

Research questions

- How acceptable is the robot compared to other delivery robots?
- How do the supportive indicators influence the predictability of the robot?

Test setup

Benchmarking appearance
The card desk that was used for the “pedestrian interviews” is used again to benchmark the design compared to other robots. The participants are asked to rank the delivery robots from what they prefer least, till what they prefer the most, to come across on the sidewalk. After the participant has put the robots in order, it is asked what criteria they used.

Supportive robot cues
The scenario that is played in VR, plays in a night setting to better see the lights, especially the lights on the bottom of the robot. There are very few pedestrians in the environment, since the robot moves on a preprogrammed path, instead of social forces. It moves towards the participant. It will indicate that it will take a turn to its right by slightly moving its body in that direction and blinking with its indicator. Before taking a stop, the robot will lean forward and the lights on the bottom will turn red. After a second, the robot leans back, the lights on the bottom turn white again and the robot will start driving. It then leans left and blinks with its indicator, before taking a left turn again. The participants are then asked a few questions about how they experienced the scenario.

Figure 51. Ranking of the robots by the participants, including the concept design.

Results

Overall benchmarking

As can be seen in figure 51, there is the same split visible as in figure 13, with robots ranked in the mid-range and some robots ranked significantly higher. The concept design is ranked within this higher category, scoring in between the PostMates and the Starship robot.

Discussion

The appearance benchmarking is only based on one image of the formgiving and not on the interaction. Participants might pick robots that seem more fun, instead of that robots that don't bother them over longer periods of time. Also the specific image chosen influences the result. The concept design was rendered, while all other robots were photographed. The render was not of high-quality and it is likely that the participants noticed that this was the concept design.

The subtle leaning of the robot was tested at the same time as the lights on the bottom. This is how the robot is currently designed, in which small cues on top of each other make the robot more predictable. However, it is very likely that on first encounter you only notice the more obvious lights on the bottom. It was not tested if pivoting of the body is a cue which is helpful over time.

Conclusion

How acceptable is the robot compared to other delivery robots?

The concept design scored better on acceptance than the PostMates robot and lower than the Starship robot, based on its appearance. The robot is seen as kind with a simple design. In agreement with the other user test, people would in general accept the robots, except in certain scenarios like busy streets or narrow sidewalks. The robot should not be in the way too much. One important aspect for acceptance is the design of the eyes. Some participants saw it as an added value and it gives the feeling that the robot is sensing the environment. However, there were multiple participants that expressed that it was too much for them. It is not necessary and the robot could better have more business-like static eyes.

How do the special indicators influence the predictability of the robot?

The red lights on the bottom are very clearly visible, especially when it is dark outside. Since the robot was braking after that, the two were easily associated with each other. After a few encounters, pedestrians will be able to predict that the robot is about to stop. The red lights can have the meaning of braking lights, however, due to the unexpected position of the lights, their meaning could also change into emergency lights. Due to the intensity some people see the lights as a signal that something is wrong with the robot. A redesign should be made with less intense lighting, a different color or a smoother animation. There are no significant results on how the pivoting of the robot makes it more predictable. In general, most people don't notice it at first encounter. Some people that did notice it, saw it as playful, but also too dramatic. This can be explained by the pivot, which is not only performed earlier than the natural pivot, but also making the natural pivot more dramatic. As a recommendation, the pivot should only be performed early, but not increasing the overall intensity of the pivot.

Other insights

All participants noticed the eyes which were moving around. They assigned different functions to them. Often it was seen as perceiving the environment, but some participants thought it was looking in the direction in which it was going. For the later, it didn't seem to cause significant confusion.

The eyes also did cause difference in the meaning that was assigned to them. Due to the increased humanness that is induced by the eyes, the anthropomorphizing effect increases. People will assign emotions to the robot. So although the eyes could move quite neutrally, if the robot maneuvers around in an insecure way, the eyes that look around are also seen as insecure. As if he is looking at the environment, not knowing what to do. First of all, the maneuvering of the robot should already look confident and this should be matching with neutral eyes or eyes that also give a sense of confidence. The effect of eye animations should be researched further, to understand their effect on perception.

Since the scenario had a very basic preprogrammed movement. Some participants noticed the difference with the social forces model. This robot didn't decreased it's speed before turning. Since normal vehicles always do this, the behavior was even perceived as an acceleration while turning. The social forces model automatically regulates this deceleration before turning, due to the length of the sum force being smaller when opposing forces are acting on the robot.

Feasibility

In this chapter, the technical feasibility is reviewed, as well as the cost of implementing the design features.

Technical feasibility

Social forces
Thanks to the simulations made in Unreal Engine 4, it is now validated that the robot could function based on social forces logic. The robot was implemented with realistic vehicle and physics behavior. It therefore operates based on specified wheel turning angles and acceleration specifications, making it significantly realistic.

The designed social forces movement is relatively straightforward, but it already proves that it capable of facilitating desirable behaviors. However, if implemented it will be part of a system, which will also consist of more traditional programming to facilitate safety features and special operations like overtaking. The system should also consist of a computer vision system that recognizes objects in the environment and potentially their movement behavior. Elderly for instance walk differently than children. This could be taken into account by the robot in the way the social forces parameters are used. The computer vision system would also be the first step in recognizing the position, speed and path of a pedestrian. This is the basic input needed for the social forces model.

Within this whole system, the computational power needed by the social forces calculation is relatively low. During the simulation, the gaming laptop used was capable of running 20 times per second through the model for 1 robot and 10 pedestrians, calculating all entities in a radius of 5,5 meters, while also rendering out the graphics at 60 fps. This proves that compared to other robot logic, there is no significant increase in performance needed when implementing social forces logic.

Gradient panel
The gradient on the front has an easthetical function, which makes the device more modern and one integrated whole. However, it induces a production challenge. In figure 52, three possible embodiments can be seen. Option 1 is a powder coated gradient on the yellow part. The transparent screen protects this coat. Option 2 is a powder coat on the transparent part, this might be easier to produce, since it is a smaller part, with less surfaces that need to be taped to protect from getting coated. Option 3 is an adhesive decal on the yellow part. Since this will be the easiest to produce and will yield minimal production faults, this would be the best option. Due to the transparent sheet in front, people will not see that the surface is slightly different than the body. It is important to use UV-resistant decals, to guarantee the aesthetic over time.

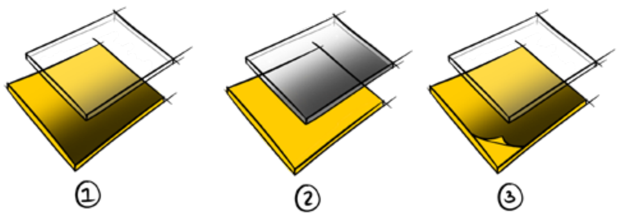


Figure 52. Gradient panel embodiment: 1. Powder coat on yellow, 2. Powder coat on transparent, 3. Adhesive decal on yellow

Cost price

The cost price of the robot can not be seen independent from the efficiency it has it the complex logistics system it takes part in. This system level design is out of the scope of this project. We therefore perform a cost analysis related to the robot's features and the resulting performance at basic tasks and the effect on positive interactions with pedestrians.

Developing a delivery robot and implementing it in society will be a huge investment. It is up to DHL to determine what cost per unit is desirable in the system that they will design. Below, an estimation is made of the cost per feature of the robot and a recommendation is given on what features to compromise on first and which should definitely be implemented.

Calculations are made based on a total production of 2000 robots.

Social forces
The relatively short amount of time needed to reach the current design of the social forces behavior, is a promising view on how much needs to be invested to implemented it in a real robot. It will still be a multi-year venture, in which more validation is needed to test the desirability, physical prototypes should be made and the model should be designed in detail.

At this stage, it is not possible to give an estimation of the financial implications of the development process. It depends on how deep the model will be integrated in the final system. It could be the fundamental movement logic where the robot depends on. In that case there will be many challenges to make it function correctly in a large variety of situations. If the model is only used on top of standard logic, it will only facilitate straightforward situations and will be cheap to implement. The same investment might be needed to develop safe standard logic. Further research should be done at what level the social forces can best be integrated.

Another topic for research is to see if there is an efficiency increase or decrease because of the social forces. A few procent increase in delivery efficiency can generate large profits. Some simulations were performed, comparing the delivery speed of a robot that keeps an almost straight line, with the social forces robot. In figure 53 can be seen that in the simulations there is no significant difference between a static and dynamic robot going from A to B. In general a static robot takes the shortest way and is therefore quick, as long as no pedestrians are in front of it. The dynamic robot takes a longer path, but often needs less decelleration.

	Time for scenario 1 till 5					Total (s)
Static robot	32.8	31.0	32.7	31.0	31.0	158.5
Dynamic robot	30.2	31.7	32.6	31.2	31.2	158.7

Figure 53. Time needed to get from the starting point to the end point, with different pedestrians arrangements.

Dynamic eyes
An external animator would be needed to design eye movements. This animator will have more knowledge about what animations result in the desired feeling for pedestrians. A typical 2D animation of one minute with two characters could cost between 5.300 and 8.900 euro (Kucharska, 2018). However, animations implemented in a physical embodiment and different perceptions of people about them, based on the scenario, will result in design challenges that are new to animators. More research will be needed beforehand, as well as collaboration with designers, user tests and multiple iterations. This could result in a total development cost of 30.000 to 35.000 euro. Resulting in about €17,50 investment per robot.

Suspension
The suspension makes sure the robot can go up a small elevation and facilitates the pivoting cues of the robot. Two variants of the “legs” are needed.

0.4kg x 4 = 1.6kg PP x €1,50/kg (Edupack, 2018) = €2,40
Steel mould: €20.000 / 2000 x 2 variants = €20,00
Injection moulding 0.01h x €45,00 (Thomassen, 2015) x 4 parts = €1,80
Stepper motor: €4,80 (Fude, 2019) x 4 = €19,20
Other controlling and stabilizing parts: €10,00
Total suspension assembly: €53,40

Gradient front panel
If a gradient on the front is implemented, there is an additional transparent panel needed and an adhesive gradient decal. A transparent part is also needed if there is no gradient, but that costs would be lower.

2.5kg PC x € 2,20 (Edupack, 2018) = €5,50
Steel mould: €30.000 / 2000 pieces = 15,-
Injection moulding 0.05h x €50,-/h (Thomassen, 2015) = €2,50
Decal 0.5m2 x €2,00/m2 (Shenzhen Shengcai Advertising Co., 2019) = €1,00
Applying decal 0.1h x €30,00/h (Thomassen, 2015) = €3,00
Total gradient assembly: €27,00

Sliding lockers
To operate smoothly and for a long period of time, a sliding locker should be equipped with linear guide rails and an actuator assembly.

Sliding mechanism: €0,30 (Yingda, 2019) x 27 lockers = €8,10
Stepper motor: €1.22 (Bobet, 2019) x 27 lockers = €32,94
Total sliding locker assembly: €41,04

Implementation priority
As a recommendation to DHL, a suggested order of implementation is as stated below. The order is from most value creating to least value creating.

1. Social forces might be the most game changing design feature that could improve interactions and therefore the brand perception of DHL by society. Therefore, it is suggested to start research and development or a collaboration with the TU Delft to explore the field.

2. The suspension is an expensive set of assemblies, with its €53,40. However it performs both functional functions as adding to the overall feel and understanding of the robot. It is therefore suggested to implement the suspension in the design.

3. The dynamic eyes could increase the comfort by pedestrians significantly. However, it is a more high risk feature, since there will be people reacting negatively on them. The benefit of the feature is that it could also be implemented at a later stage, if there is a multi-purpose display implemented.

4. The gradient front panel could cost €27,00 to produce. Since it only has the function of making the design more modern and look more integrated, it might be one of the first aspects to compromise on. The costs of the gradient could also go down if the transparent panel is only applied in front of the sensors and the rest is a powder coated shiny yellow plastic. It would then need an extra protection coat against wear and the overall appearance is less reflective and modern.

5. Sliding lockers are a significant investment of €41,04 per robot. Since it has no effect on the functioning of the robot, and only little on the perception of comfort by pedestrians, it is suggested to stick with the door-like lockers that DHL already uses.

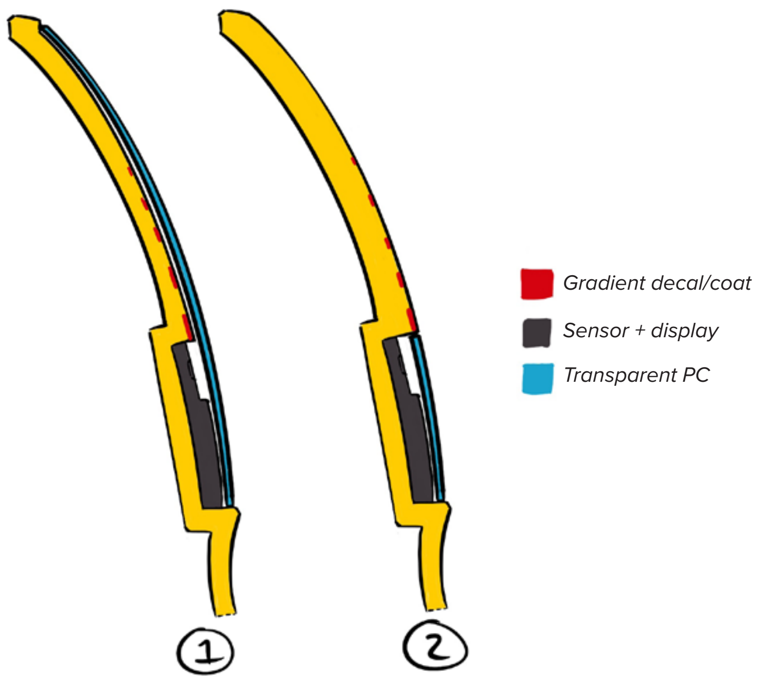


Figure 54. 1. Original gradient front panel design. 2. Alternative gradient front panel design.

Viability

Timeless design
Within the design process, care was given to shape the robot into a neutral design, that feels business like and therefore fits within the product portfolio of DHL. The design is both simple and modern and is likely to not get outdated within a few years. Pedestrians will probably not get tired of the design too quickly.

Durability
The body of the robot is made of one rigid assembly. There are no loose parts which are likely to get vandalized. However, there are some parts of the design that need extra attention in the further design process. The suspension and wheel assembly has rotations in multiple directions. It is therefore more prone to wear over time. These parts should be rigidly designed, to handle normal use scenarios as well as mild vandalism, like kicking the wheel assembly.

The large transparent panel on the front serves as a protection of the expensive sensors, the display and the gradient, against theft and getting dirty. However, it is a tempting surface for people to scratch or besmirch. DHL could make this part easy to replace and implement for instance an anti-graffiti coating.

Functionality
The suspension of the robot makes it possible to diagonally go up a step. This allows it to operate in a wider variety of environments. However, the wheels are not wide enough to drive on unhardened surfaces like sand. Since the robot is most likely to first be implemented in easier to navigate in neighborhoods, going up steps might not be needed yet. If the robot will at a later point be implemented in more complex environments, like cities with older infrastructure, it has the suspension to navigate uneven surfaces.

For the wheel setup there is chosen for a four wheel setup, with turning wheels. This is needed since a heavily loaded vehicle would cause more wear on the wheels if it would pivot around it's axis. It would also create a more unpredictable movement of the body. The down side to a four wheel setup is that there is a minimum turning radius. This could create problems in real life scenarios in which the robot navigates narrow one-way sections, like an elevator. It should first be researched what turning radius is needed to function properly in urban environments and if this turning radius is possible within a suspension assembly. The benefit of the current design is that also the back wheels can steer.

Discussion

A final concept design is always depending on the approach taken within the project. In this chapter, the influence of the design process is analyzed, as well as the efficiency of using virtual reality within the design process.

Influence of virtual environments
Since delivery robots are not ambiguous in real-life, it was hard to discuss with future users how they perceive them. People find it hard to imagine them and how it impacts their experiences on the sidewalk. Using virtual environments turned out to be a game changing way of prototyping. It allowed to make the robot visual in a simulated context and to test a broad range of aspects at the same time. With physical prototyping it would have been possible to create a prototype to test indicators, or the movement, but everything at the same time, including the actual formgiving and physical behavior of the design, would not have been possible.

However, virtual environments have their limitations for user testing. This project creates more insights in how to use VR in a research environment. The interactive aspect of the tests greatly influences the test setup. As experienced with the first VR user test, the results of a scenario is not always comparable between participants, since different interactions create different experiences.

Overall using Unreal Engine 4, created a more profound process in which the developed prototypes were able to be used in different ways. The virtual environment, pedestrians and robot were able to be used for visualization, testing and simulating. Actually immersing people into the simulations was a cutting edge method that created a lot of insights. Insights were due to the level of realism not only answering the research questions, but also touched upon unexpected aspects.

Robot intelligence
From the start, robot intelligence was one of the three main pillars of the project. It was a challenging aspect, in which the best approach was not found until far beyond the mid-term meeting. It was a personal struggle to find an approach that did not assign artificial intelligence as the technology that will fix the whole problem and to find a direction in which I as a designer can have a significant impact. Using the social forces model turned out to be a great approach that is able to solve the problem. During the research phase the social forces model was already analyses and it was later used as an experiment. However, there was no well considered selection procedure in which other methods were analyzed as well. More methods should have been researched to find the best way to integrate human behavior onto a robot.

This project proves that the robot would be able to operate based on social forces. However, it only provides a first experimental inquiry. More in depth research is needed in:

- What specific behavior is most efficient and acceptable.
- How the model fits withing the overall robot's logic.
- How it operates in specific scenarios.
- How the model can be used to optimise interactions.

Robot acceptance
The whole project is focusing on improving the acceptance of delivery robots. However, there is no quantitative method used to define how acceptable the robot actually is. The concept design might be more accepted by people than already existing robots, but the absolute acceptance could still be negative. In the different user tests, the attitude of people towards these robots are tested. The results are moderately positive, however, in real-life implementation the robot will come across a wider variety of people with different attitudes. A few people with a negative attitude towards the machine might influence the general attitude in society.

Influence of culture
The scope of the project is the Dutch society. Different cultures will look differently to robotic technologies and have different preferences on the aspects of the dRAM model. For instance, Chinese people are more open to intelligent technologies and technologies that are more human. The robot might not function the same there as in western countries. The maneuvering or the way it expresses emotion could be different.

Conclusion

Once again we look back at the dRAM model and how well the final concept design is able to match the needed characteristics. Also the design goal is evaluated again to see if the concept fulfills the goal. Recommendations are given for future research and development.

Overall conclusion

In straightforward situations, the robot can make use of social forces logic. To enhance the understandability of the robot during these social forces movements, there are some small cues used. If the robot is decelerating to a full stop, the lights on the bottom will turn red and the body will pivot forward. On the back, the braking lights will brighten. Before accelerating, it will turn its lights white again and pivot its body backward. The robot also tilts its body sideways into the direction that it will go into, just before it actually does it. The orange blinking light is not used with small movements, but only to indicate a large change in direction or when communicating with people in vehicles.

The research and designing in this project is a first step into designing a comfortable autonomous last-mile solution. Literature research was done on acceptance of robotics, which pointed in the right direction, but often had a difference in context. Most literature was about robots with a social-emotional function in the home environment or mechanical robots in manufacturing. The context of a delivery robot is different, for instance the interactions with delivery robots are arguably better if there is as less interaction as possible and the pedestrian is not necessary the user of the service.

The research performed in this project, which was heavily based on virtual reality technology, created much new insights into how pedestrian-robot interactions on the sidewalk will actually unfold. It was therefore a critical method to go from interactions based on indicators to interactions based on flowing movement. Within this project, the first steps were made into researching the possibilities of implementing this human movement onto robotic systems. Insights were gained into how social forces parameters result in desirable robot behaviors that takes into account both the comfort of pedestrians and efficient crowd behavior. The social forces model seems like a promising way to improve efficiency and quality of interactions. Both by implementing it as standard movement logic, as for other use cases, like predicting pedestrian movement. There is a long way ahead to research this topic further.

Design goal

Functionally efficient
It's appearance is highly functionally efficient due to the rectangular shapes used and the amount of parcels it is able to transport. Detailing of the device creates associations with parcel delivery practice, like the visually separate container, which can be swapped.

Intuitive interaction
The social forces model has the potential to create intuitive interactions. It is definitely more intuitive than using intent indicators in the context on the sidewalk. This clearly created hesitant behavior and more confusion. A robot moving with social forces is constantly reacting on the environment, which creates a constant cue of what it is going to do.

It should be researched further what the effect of this movement is in real-life scenarios and in the long-term. It might be necessary to implement dynamic robot behavior over time. The parameters of the social forces model could be updated over time, so it starts with a more static movements and periodically gets updated to more human behavior. However, this should not result in pedestrians getting confronted with significantly new behavior very often. The change in interaction could be with small update spread out over a longer period of time, changing interactions unconsciously. Or it could be updated in a few big steps, possibly communicated to society by advertisement campaigns.

Feeling of control
As described earlier, the feeling of control can be added in multiple ways. It was strived for a robot which looks and behaves trustworthy. But pedestrians can actively take more control, due to the social forces movement of the robot. Pedestrians will notice that the robot adapts to their behavior and if needed, they can therewith steer the behavior of it.

The other way around, the robot can also take control in situations, in which it predicts to have a positive impact on the overall situation. This should be used with caution, since it is decreasing the control of pedestrians. However, when performed correctly, it could result in more comfortable interactions and possibly more trust in that the robot takes good decisions.

dRAM

See figure 55 for the final hypothesis of how the factors in the dRAM model should be implemented in the design.

Perceived usefulness
Making the robot feel useful is complicated to achieve. Pedestrians are not direct user of the service. It is recommended for DHL to look into implementing a service which can be used by pedestrians at all times. For instance, on-demand parcel posting.

The appearance of the robot increases the perceived usefulness slightly by communicating clearly what the robot is, by the logo on the side and the visible locker system. In the current design there is room for 27 parcels. Compared with the size of the robot, this gives an efficient feeling. There need to be few robots implemented into society to get great amounts of work done.

Perceived ease of use
The design does increase the perceived ease of use. The wheels are clearly visible by the higher body and the lights on the bottom. It communicates to what behavior the robot is capable. Since the robot has four wheels it always has a predictable and fluent turning radius, compared with robots that jiggle when pivoting around their axis.

The human-like social forces maneuvering is a constant visual cue that the robot is reacting on its environment. This consistency in reacting to it's environment already creates an understanding for pedestrians when the robot is interacting with other pedestrians.

Perceived humanness
The humanness should be somewhat consistent throughout the whole design. The slightly human look of the suspension and body and the clear facial elements on the front create the expectation that the robot has a reasonable amount of intelligence. It is clearly more human than current vehicles and especially the moving eyes give the feeling that the robot is perceiving and acting on the environment. This intelligence can be seen in the way it uses social-forces to maneuver. It is more human in it's movements and pedestrians will over time react more to the robot as if it moves like a human.

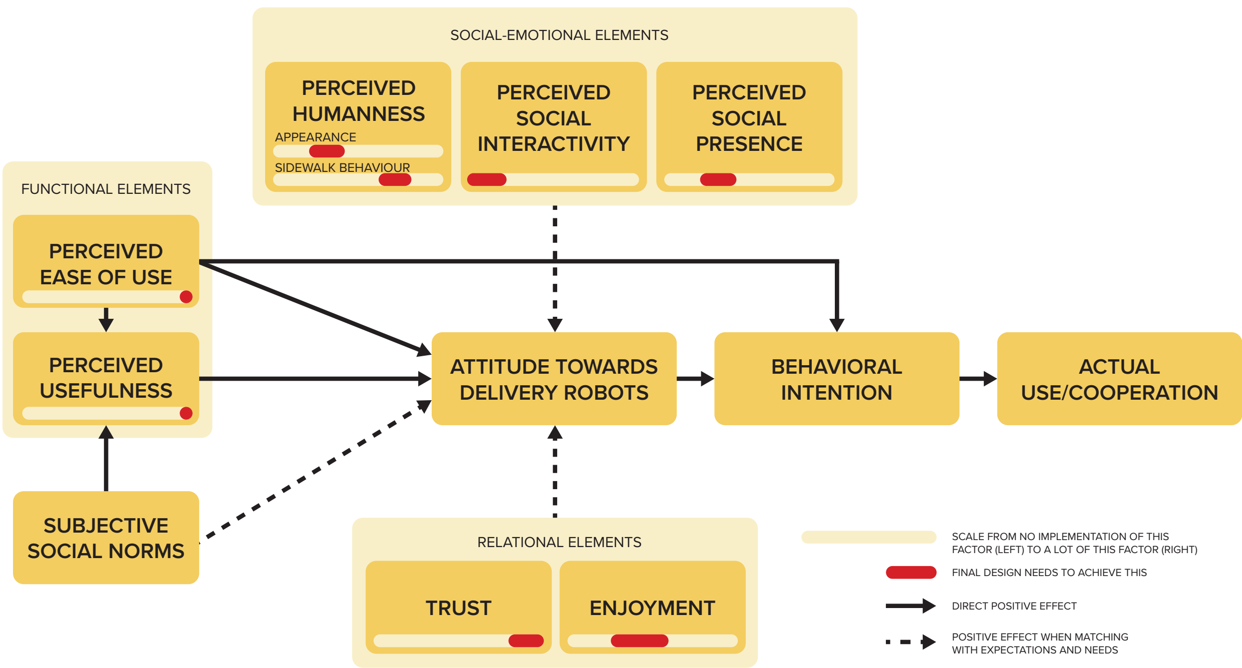


Figure 55. dRAM with the final hypothesis of how much of each factor should be implemented.

It is arguable that most of the design is currently at the level of humanness that people prefer. However, the dynamic eyes are very novel for people. The second user test showed that the opinions were differing on this part. For some people it was too much and not necessary. Others saw the added value and liked it. This should be researched further. For DHL I would suggest to only implement dynamic eyes, if enough effort is being invested into researching the effect of the specific animations and what animations to implement in which scenarios. People's interpretations of the animations are vastly different based on the context and the way the robot behaves. If implemented incorrectly, eyes could emphasize negative aspects of the robot, like making the robot look unsure about what it is doing. The robot could first be implemented with static eyes and at a later point could be updated with eye movement.

Perceived social interactivity
The humanness in it's interactivity is relatively low. It does not communicate verbally and only with facial expressions. Generally the eyes look around into the environment to objects and people it needs to take into account. The only interactivity is when it for instance blinks at a pedestrian as a form of recognition. Since it is a service robot without a social-emotional function, this is enough. Most pedestrians are not in need of verbal communication with a robot or would be uncomfortable by it.

Perceived social presence
The robot is only present in the way that the eyes show that it is taking into account everything in the environment and that the social forces make the robot react constantly on its environment. It will not be very socially present. It should be researched further if there is a need for more social presence, if for instance, people would start talking to the robot. It might need to give a sign of recognition with its eyes or body movement, or with an audio cue.

Trust
How trustworthy the final robot will be, is very dependent on how it can cope with different situations. The social forces model is widely applicable, but it should be optimized and extended to function trustworthy in every possible scenario. It is arguable that a very static robot is more trustworthy in the short term, since it is very predictable and matches with the expectations about robots. However, the social forces model has the potential to build trust over time. Pedestrians will know that the robot reacts in a certain way on their behavior. It is constantly adjusting to its environment, which acts as a continuous cue that it will also react to you when it approaches.

The level of humanness, especially the eyes improve the trust in the robot, because it is perceivably intelligent in acting safely in it's environment.

Enjoyment
The facial elements create more joy than very mechanical robots. However, it is not intrusive and easily ignored by people that don't want to be distracted by the robot.

A robot moving based on social forces is more fun to interact with than a robot that moves very static and needs more adaptation by pedestrians.

References

Amherst, U. o. (n.d.). Retrieved from https://people.umass.edu/aizen/sn.html

Bar, M., Neta, M., & Linz, H. (2006). Very first impressions. Emotion, 269-278.

Bartneck, C. (2003). interacting with an Embodied Emotional Character. Proceedings of the Design for Pleasurable Product Conference, 55-60.

Bartneck, C., Suzuki, T., Kanda, T., & Nomura, T. (2009). The influence of people's culture and prior experiences with AIBO on their attitude towards robots. AI & Society, 217-230.

Bates, J. (1994). Role of emotion in believable agents. Communications of the ACM, 122-125.

Beer, J. M., Prakash, A., Mitzner, T. L., & Rogors, W. A. (2011). Understanding Robot Acceptance. Atlanta: Georgia Institute of Technology.

Beer, J., Prakash, A., Mitzner, T., & Rogers, W. (n.d.). Understanding Robot Acceptance. Atlanta: Georgia Institute of Technology.

Bobet, S. (2019). Alibaba. Retrieved from https://dutch.alibaba.com/product-detail/86-filaments-within-the-rod-through-60492539330.html?spm=a2700.7724838.2017115.390.76a448dbnacJ5b

Breazeal, C. (2002). Designing sociable robots. Cambridge: MIT Press.

Breazeal, C. (2003). Emotion and Sociable Humanoid Robots. International Journal of Human Computer Interaction, 119-125.

Breazeal, C., Brooks, A., Chilongo, D., Gray, J., Hoffman, G., Kidd, C., . . . Lockerd, A. (2004). Working collaboratively with humanoid robots. Proceedings of IEEE-RAS/RSJ International Conference on Humanoid Robots, 253-272.

Broadbent, E., Stafford, R., & MacDonald, B. (2009). Acceptance of healthcare robots for the older population: Review and future directions. International Journal of Social Robotics, 319-330.

Collier, G. (1985). Emotional expression. Hillsdale: Laurence Erlbaum Associates Inc.

Darling, K. (2015). "Who's Johnny?" Anthropomorphic framing in human-robot interaction, integration, and policy.

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly, 319-340.

Edupack, C. (2018).

Ezer, N. (2008). Is a robot an appliance, teammate, or firend? Age-related differences in expectations of and attitudes towards personal home-based robots. Atlanta: Unpublished Dissertation.

Ezer, N., Fisk, A., & Rogers, W. (2009). Attitudinal and intentional acceptance of domestic robots by younger and older adults. Proceedings of the 2009 International Conference on Universal Acces in Human-Computer Interaction.

Fude, G. (2019). Alibaba. Retrieved from https://dutch.alibaba.com/product-detail/Nema17-Threaded-Shaft-Lead-Screw-30mm-62125673494.html?spm=a2700.7724838.2017115.21.20396d63eSLKj1&s=p

Goetz, J., Kisler, S., & Powers, A. (2003). Matching robot appearance and behavior to tasks to improve human-robot cooperation. Proceedings of the 2003 IEEE International Workshop on Robot and Human Interaction Communication, 55-60.

Graaf, d. M., Allouch, S., & Dijk, v. J. (2016). Long-term evaluation of a social robot in real homes. Interaction Studies, 1-25.

Graaf, M. M., Allouch, S. B., & Dijk, J. A. (2019). Why Would I Use This in My Home? A Model of Domestic Social Robot Acceptance. Human-Computer Interaction, 115-173.

Hekkert, P., & Cila, N. (2015). Handle with care! Why and how designers make use of product metaphors. Elsevier.

Helbing, D., & Molnar, P. (1998). Social force model for pedestrian dynamics. Stuttgart: Institute of Theoretical Physics, University of Stuttgart.

Hinds, P., Roberts, T., & Jones, H. (2004). Whosejob is it anyway? A study of human-robot ineraction in a collaborative task. Human-Computer Interaction, 151-181.

Hjelm, S. I. (2002). Semiotics in product design. Stockholm.

Kahane, J. (2015). The Form of Design. Amsterdam: BIS Publishers.

Kanda, T., Miyashita, T., Osada, T., Haikawa, Y., & Ishiguro, H. (2008). Analysis of humanoid appearances in human-robot interaction. IEEE Transactions on Robotics, 725-735.

Kim, T., & Hinds, P. (2006). Who Should I Blame? 1.

Kucharska, G. (2018, 01 05). Studio Pigeon. Retrieved from https://www.studiopigeon.com/blog/how-much-does-it-cost-to-produce-animation-and-why/

Michael Eaves, D. G. (2018). Successful Nonverbal Communication - Principles and Applications. New York: Routledge.

Mori, M., MacDorman, K., & Minato, T. (2005). Bukimi no tani. The uncanny valley. Proceedings of the Humanoid-2005 Workshop: Views of the Uncanny Valley, 33-55.

Nass, C., Steuer, J., Henriksen, L., & Dryer, D. (1994). Machines, social attributions, and ethopoeia: Performance assessments of computers subsequent to 'self-' or 'other-' evaluations. International Journal of Human-Computer Studies, 543-559.

Pagallo, U. (2013). Robots in the cloud with privacy: a new threat to data protection. Computer Law & Security Review, 501-508.

Reddit/ofcoursethatsathing. (2018). Retrieved from https://www.reddit.com/r/ofcoursethatsathing/comments/9q1yzc/food_delivery_robot/

Reddit/postmates. (2019). Retrieved from https://www.reddit.com/r/postmates/comments/a6kcsm/postmates_reveals_its_cute_automated_delivery/

Reddit/technology. (2018). Retrieved from https://www.reddit.com/r/technology/comments/8ps7sa/people_kicking_these_food_delivery_robots_is_an/

Rogers, E. (2003). Diffusion of innovations. New York: The Free Press.

Rosenthal von der Putten, A., Kramer, N., & Herrmann, J. (2018). "The effects of humanlike and robot-specific affective nonverbal behavior on perception, emotion and behavior". International Journal of Social Robotics.

Rouse, M. (n.d.). SearchEnterpriseAI. Retrieved from https://searchenterpriseai.techtarget.com/definition/robot

Shenzhen Shengcai Advertising Co., L. (2019). Alibaba. Retrieved from https://dutch.alibaba.com/product-detail/Bulk-Production-advertising-PP-Poster-decal-60780958019.html?spm=a2700.7724838.2017115.31.3eba56ffM0V81Z&s=p

Siegel, D. (2008). Changing Minds. Retrieved from http://changingminds.org/explanations/needs/control.htm

Sung, J., Grinter, R., & Christensen, H. (2009). "Pimp My Roomba': Designing for personalization. Proceedings of ACM Conference on Human Factors in Computing Systems, 193-196.

Taherdoost, H. (2017). A review of technology acceptance and adoption models and theories. Procedia Manufacturing, 2.

TechCrunch. (2018, May 25). Youtube. Retrieved from https://www.youtube.com/watch?v=eGNpqvHAydE

Thomassen, E. (2015, 03 30). Kostprijsopbouw 2015. Delft.

Tielman, M., Neerincx, M., Meyer, J., & Looije, R. (2014). Adaptive emotional expression in robot-child interaction. International Conference on Human-Robot Interaction, 407-414.

Tinwell, A., Grimshaw, M., & Williams, A. (2011). "The uncanny wall". International Journal of Arts and Technology, 326-341.

Torrey, C., Powers, A., Marge, M., Fussel, S., & Kiesler, S. (2006). Effects of adaptive robot dialogue on information exchange and social relations. . Proceedings of the Third ACM IEEE International Conference on Human-Robot Interaction, 126-133.

Wirtz, J., Patterson, P. G., Kunz, W. H., Gruber, T., Lu, V. N., Paluch, S., & Martins, A. (2018). Brave new world: service robots in the frontline. Journal of Service Management, 907-931.

Woods, S. (2006). Exploring the design space of robots: Children's perspectives. Interacting with Computers, 1390-1418.

Yingda, L. (2019). Alibaba. Retrieved from https://dutch.alibaba.com/product-detail/Europe-style-drawer-slide-side-mounted-

Youtube. (2017). Retrieved from https://www.youtube.com/watch?v=wGDNejAQo6Q

Youtube. (2018). Retrieved from https://www.youtube.com/watch?v=ujzjZuhE92g

Zeng, W., Yu, G., Chen, P., & Wang, Y. (2017). Specification and calibration of a microscopic model for pedestrian dynamic simulation at signalized intersections: A hybrid approach. Transportation Research Part C Emerging Technologies.

Appendix

A. Design brief

B. dRAM motivation

C. Workshop PostBot team

D. Pedestrian interviews

E. Indicator and gesture user test

F. Robot behavior simulation

G. Social forces and cues user test

dRAM motivation
Appendix B

The “Technology Acceptance Model” (TAM) is used often in literature. However, for the use on robots which could have social-emotional elements, the TAM is limited. The most important insight from the TAM are perceived usefulness and perceived ease of use are the main beliefs that form the basis for customers attitude (Davis, 1989). From their attitude they form a behavioral intention, which could predict the actual use. Perceived usefulness also has a direct influence on the behavioral intention.

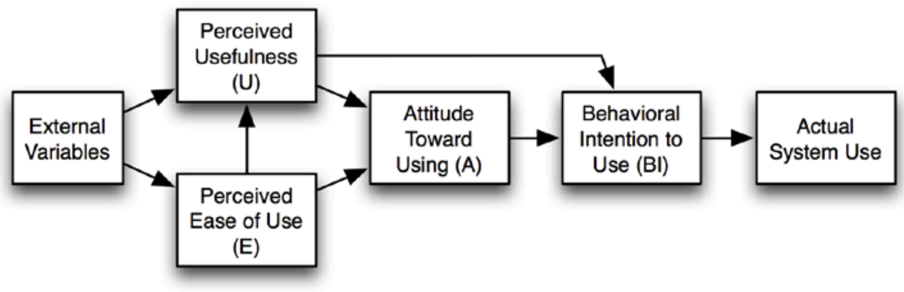


Figure B1. TAM

A better fitting model for the context of delivery robot is the “Service Robot Acceptance Model”. It concerns with the functional elements from the TAM and includes social-emotional elements and relational elements (Wirtz, et al., 2018).

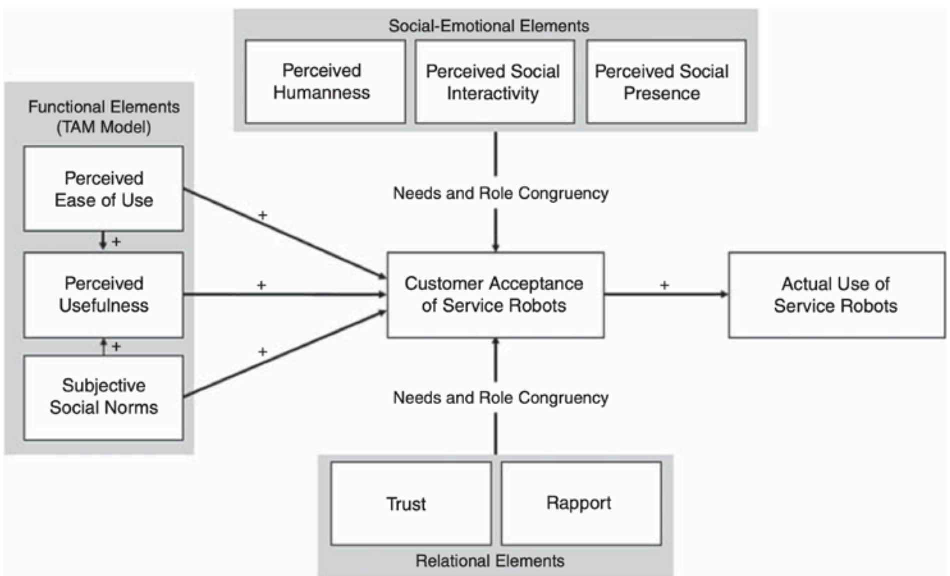


Figure B2. sRAM

The sRAM is a more comprehensive model, but it neglects the sequence of forming attitudes, forming a behavioral intention and actual use. Based on the sRAM and combined with this sequence from the TAM a new model was formed to support this project, the “Delivery Robot Acceptance Model” (dRAM).

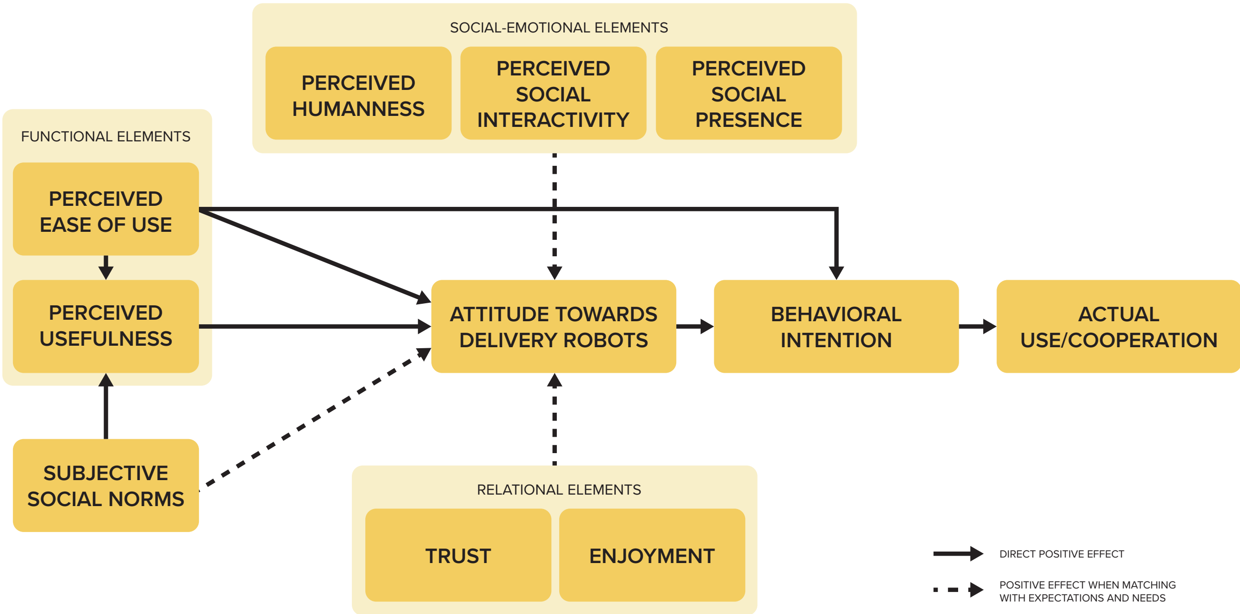


Figure B3. dRAM

Some changes applied in dRAM:

- In dRAM the subjective social norms are separate from the functional elements, since this one didn't seem to belong in that category.
- Rapport was freely translated into enjoyment, since it is easier understood.
- The delivery robot should be matching with the subjective social norms experienced. In sRAM this is a direct positive effect, but literature describes otherwise.
- The last step in model is translated into "actual use/cooperation" since the robot is not necessarily used by pedestrians.

Workshop PostBot team 14-02-19
Appendix C

On the 14th of February, a session with three employees of Deutsche Post was conducted. They were all involved in the development of the PostBot. The PostBot is a device that can follow the mailman on his task of delivering letters. It has space for 8 trays filled with letters. With its maximum capacity of 150 kg, it is able to make the mailman's work more comfortable.

Figure C1. The PostBot

The goal of the session was to learn from the design choices that were made during the development of the PostBot and how the device functions in reality. This can help to make quick decisions on physical design choices for this project. For instance, the way to set up the wheels and what dimensions would be suitable. The second goal was to get inspiration from their opinion on robot design and interaction. The last goal was to test methods to have a good conversation about attitudes towards delivery robots. Suitable methods can be used in the upcoming pedestrian interviews.

Method
The session was set up around three creative activities. These were to open up the discussion and to cover the different questions that were set up beforehand. To retrieve both insights on the PostBot and on their opinions on developing a fully autonomous device, the general assignment of the session was to create an overview of what would change about the PostBot if a fully autonomous version would be made.
Brainstorm on challenges
A brainstorm was performed to find challenges with developing a new version of the PostBot that works fully autonomous. The participants were asked to write down on Post-It notes their ideas and inform the group about them.

Visualizing bad and good robots
The participants were asked to doodle, draw or write out the characteristics of the worst robot that they could imagine. The same task was given for the best robot imaginable. They were not guided in the type of ideas to generate, so they could come up with ideas on form, function and behavior.

Emotional response on form
The last part is a discussion based on a deck of cards. The card desk consists of:
• 8 cards with pictures of existing delivery robots.
• One card with the question: “When encountering a delivery robot on the sidewalk, I want to feel:........”
• 18 cards with examples of emotions.
• Multiple cards with: “Important robot quality:...........”.
• 10 cards with examples of robot qualities.

After laying the 8 cards with existing robots in front of them, the participants where asked for their opinion and their emotional reaction to them. They were asked to put the cards in order from least preferred to encounter on the sidewalk to most preferred. Thereafter they were given the card at which they could fill in how they would like to feel when encountering a delivery robot on the sidewalk. If needed, they could use the examples of emotions as inspiration. The participants were asked to describe what robot qualities and characteristics are important to achieve this feeling. Again, they can draw inspiration from a set of example robot qualities.

Results
Physical design
The dimensions of the machine are length=120cm, width=80cm and height=150 cm. The wheel basis 50cm. Which in reality means that it tips over very easily. For instance, with an emergency brake, combined with a high friction surface and not much loaded weight on the device. Therefore, a wheelbase of 100cm is suggested. Tipping over on emergency brake can make the situation worse than it was. The width of the device is based on the width of wheelchairs.

Suspension is really an issue. It has no, so it sometimes doesn’t make contact with al 4 wheels on the ground. The wheels are synchronized with the distance they have to travel in a corner. The front wheels are connected to each other with an axis that can rotate. The wheels always stay perpendicular to each other. The same is true for the back wheels. This means that the two axis make a V shape while turning. This formation allows it to make small circles, but the device cannot pivot around its middle point. That is the reason why they gave the device no defined front. Often the device needs to go backward because the pathway is too small to turn. It has a light bar on the front and back. The color of this bar, white or red, defines what at that moment is the front side.

It follows the person with lasers. You sync it with your legs. It follows you 360 degrees. But if you confuse the laser, it could follow someone else.

Challenges of making an autonomous PostBot
• Public acceptance can be a challenge, especially with the perception of safety.
• Guarantee safety with small children and animals.

• Some of the functionalities that are done by the mailman, will be handed over to the robot. For instance, ringing the bell, opening letterboxes and handing over the right parcel.
• The additional sensors needed for the device might make it “ugly”.
• Narrow pavements are challenging.
• A challenge with the PostBot is that it doesn’t communicate intent with pedestrians. It can for instance overtake someone, but this means that during its arc it will go straight to opposing pedestrians. This has proven to be quite problematic, since pedestrians can get scared of the PostBot driving straight towards them.
• Another challenge is with alleys or pavements perpendicular to driving direction that have hidden corners. If the employee walks past a hidden corner, the robot is not able to see what is around that corner. Its response is often not quick enough when there is an unexpected pedestrian. The way this problem is solved is by giving the mailman the responsibility to always take a halt before walking through a blind corner. An autonomous delivery robot will have the same challenge.
• Passing or crossing streets with traffic signals.
• Maneuvering through large crowds.
• People will much likely challenge the robot by jumping in front or surrounding it.

Attitude towards the PostBot
Pedestrians are in general interested. They sometimes talk to the robot: “follow me robot”.
They also often ask the mailman if the robot has a name. People in general find it cute. As one of the participants explained, it is probably because the robot has small “feet” and a short “body”. It looks like a friendly chubby man.

People challenge the robot a lot. They jump in front of it to test if it responds. This is not the best thing to do because a robot is also a mechanical system that can make mistakes and has to work with outside environments, like the resistance of the road and braking time.
They are almost never negative towards the robot.

Figure C2. The results from the brainstorm session.

Participants attitude towards delivery robots
• The participants preferred robots that had some anthropomorphic elements like eyes. The PostMates robot was for instance one of their favorites. Also, the wheels of this device are preferred. They are pretty high, which gives them good suspension and the robot look “cute”.
• The participants are getting tired of seeing the Starship robot, however they like the refined lines and they think it looks friendly. They were not really able to describe why are getting tired of it.
• In general, there was a preference for robots with a more “boxy” shape. This makes the feel efficient.
• Hard shapes, mechanical shapes and mechanical robots with animal characteristics are not preferred. They like the shape of the PostBot because of its roundness.
• They would like the idea of the robot talking to you. For instance, saying good day. It could ask you to move out of the way. This behavior creates sympathy.
• The robot is subordinate to humans. Therefore, it should always be active in keeping safe distance.

Conclusion
The insights gained about the physical properties of the PostBot can be used during the design process. These properties are not the main part of the project, so the insights gained in this session are very valuable to make educated design choices.

Some interesting interaction scenarios where raised that could be the starting point for further testing within the conceptualization phase of this project. For instance, the robot behavior when overtaking something or someone, while other people are approaching from the other side. The situation with hidden corners is also an interesting challenge to test. As well as maneuvering through crowded areas and using traffic lights.

The background from the participants should be kept in mind. They have been working on robotics for a long time. Insights about technology and their experience with the PostBot is very valuable. However, their attitude towards existing robots might be different from the average pedestrian.

Pedestrian interviews
Appendix D

All literature about robots and technology acceptance are not directly applicable to a delivery robot due to difference in context and function. Therefore, it is important to gather insights about the attitude of people about delivery robots first hand.

The goal of the sessions is to gather attitudes against delivery robots. For instance, general attitudes and concerns about this new technology, but also specific towards the form and dimensions of existing devices. Furthermore, a goal is to gather opinions about how the robot should and shouldn't behave.

Method

Interview sessions where set up with a total of 9 participants in three different age groups: students, adults and seniors. Different age groups are chosen because technology acceptance is likely to differ based on difference in experience with technology and generational differences.

The sessions took 35 to 45 minutes and were done one on one. This was done to minimize the influence of other people's opinions to influence the attitude of the individual. Audio was recorded to document their responses afterwards. The sessions consist of three parts. They focus on different parts namely: general attitudes, emotional response on form and attitude towards robot behavior scenarios. The order of the questions below was restructured after interviewing participant 7, 8 and 9. This was done to minimize the influence of earlier questions on the answers.

General attitude
The first part consists of interview questions to determine the level of experience with delivery robots, what they expect from the device and what their attitude is towards them. The interview was semi-structured. The starting point was the set of questions below.

[1] Have you ever seen a delivery robot in real life or on internet?
Explain what an autonomous delivery robot is.
[2] What do you think is the reason logistics companies will implement them?
[3] Do you think they should be driving over the road or the sidewalk?
Further questions on their motives and underlying beliefs? Are they against those devices in certain areas?
[4] Would you in general be fine with this new technology or would you prefer the current situation?
What are their reasons for this?
Explain that the devices drive over the sidewalk.

Emotional response on form
The second part is a discussion based on a deck of cards. The card desk consists of:
• 8 cards with pictures of existing delivery robots.
• One card with the question: "When encountering a delivery robot on the sidewalk, I want to feel:........"
• 18 cards with examples of emotions.
• Multiple cards with: "Important robot quality:...........".
• 10 cards with examples of robot qualities.

After laying the 8 cards with existing robots in front of them, the participants where asked for their opinion and their emotional reaction to them [5]. They were asked to put the cards in order from least preferred to encounter on the sidewalk to most preferred [6]. Thereafter they were given the card at which they could fill in how they would like to feel when encountering a delivery robot on the sidewalk [7]. If needed, they could use the examples of emotions as inspiration. The participants were asked to describe what robot qualities and characteristics are important to achieve this feeling [8]. Again, they can draw inspiration from a set of example robot qualities.

Attitude towards interaction scenarios
The last part of the session consists of their opinion on human-robot interaction scenarios seen in three videos. The three scenarios where chosen based on the outcomes from the session with the PostBot team and the session with Mr. Radetski and Mr. Beckman.

The videos where made by making a time-lapse of 5 frames per second, made from pictures of a 1:25 scale model. The video had no sound. After showing a video to the participant they are asked what they see on the video. Their opinion was asked about how the robot and humans behaved. They were asked how they would feel if the robot behaved in this way.

In scenario 1 a delivery robot approaches a group of three people [9]. They are talking and not paying attention towards their surroundings. The robot wants to pass the group of people. In an attempt to pass the group of people he tries to find a way to pass by moving back and forth a bit and moving a bit sideways. After not being able to find a way to pass the group of people, the robot turns around and goes back to where it came from. This scenario shows a robot with a subordinate behavior. The robot doesn't come too close, doesn't seem to ask much attention and adjusts its route to not disturb the group of people.

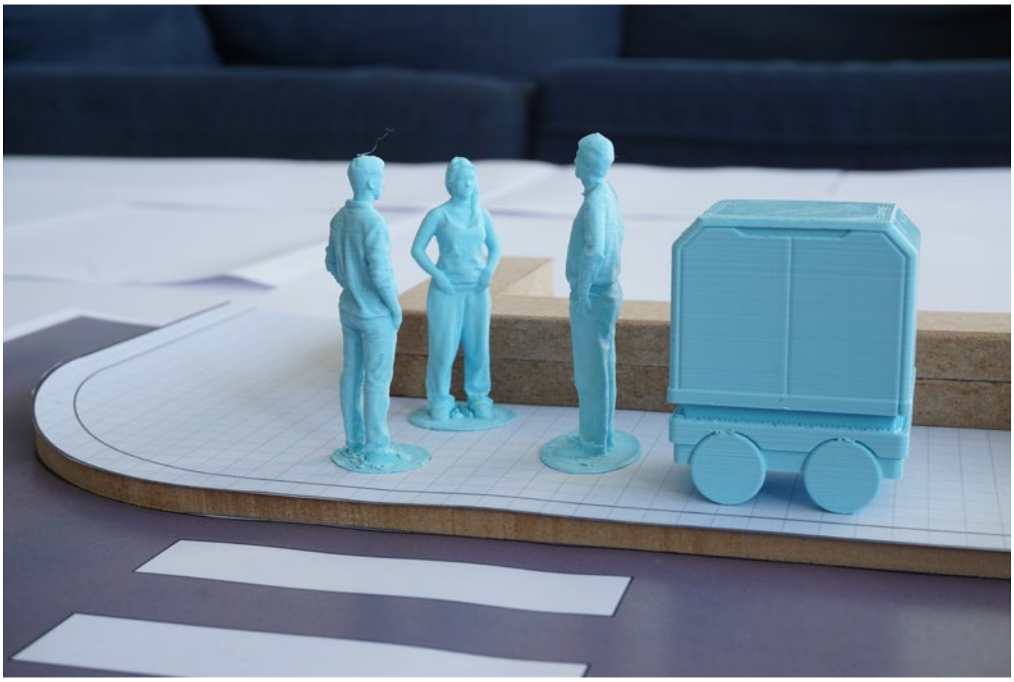


Figure D1. Scenario 1, subordinate robot behavior.

In scenario 2 the situation is very similar to scenario one. Three people are standing on the sidewalk [10]. In this case the robot has a more proactive behavior. When approaching the group it slows down, but when in close proximity to the man on the right, he tries to move around the man on the left side. In his attempt he comes very close or even touches the man, which is up to the participants to interpreted. At this point the man moves to the side, as well as the man on the left. The robot continues its path over the sidewalk.

Figure D2. Scenario 2, a proactive robot behavior.

In scenario 3 the robot moves on its right side of the pavement towards a person standing on the right side of the pavement [11]. The robot moves around the person by moving to the left side of the pavement. In its action it blocks a moving pedestrian, coming from the other side, to move on. This pedestrian takes a halt and waits till the robot moves back to the right side of the pavement. In the robots its action to pass the passive object, it moves straight towards the opposing pedestrian.

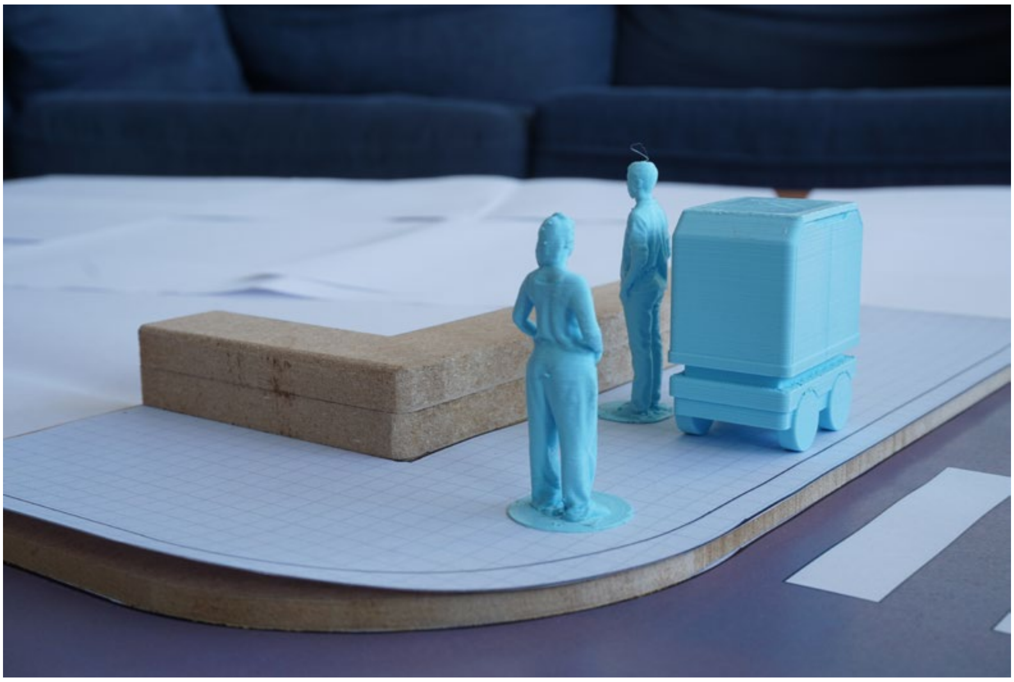


Figure D3. Scenario 3, a robot overtaking, while a pedestrian approaches.

Results

Participant 1

Male student

[1] The participant has never seen a delivery robot in real life. However, he has seen a delivery drone on the internet.

[3] It depends on how large they are, what their position in the urban environment should be. If they are too large, the participant would annoy himself, if they would drive over the sidewalk. He could imagine that people walk faster than the robot. If it would go faster, then he would think that it fits better on the cycling lane or on the road. He would prefer the devices to be on the road, because as a pedestrian, or cyclist you are more vulnerable. On the sidewalk it is also fine, but the participant would like to know what the device is going to do and how it will react. The robot could go faster than people, but when approaching them, they should adapt their speed.

[4] The participant would like the idea of this technology hitting the road. But he doubts the value of the concept. The robot might be more efficient in some tasks, but it also provokes losses of jobs. The participant doesn't like this idea, but this is always the case with new technologies. Parcels should stay affordable, though. The concept could improve the service, so more flexible and safer than the current delivery vans.

[2] A delivery robot would be cheaper in the long run. First the costs are high, but money will be saved on labour costs. The robots are probably more flexible to work with for the logistics companies and they can provide new services to their customers.

[9] "This is a little bit sad." If I would be one of those people, I would find it really uncomfortable if this "self-driving book closet" would push in my back, while I am just talking there. He is quite high, so I would feel intimidated. The participant would step aside if the robot is approaching, but the robot is interrupting the conversation quite a bit.

[10] The participant would step aside, as shown in the video. However, the robot comes very close, which is really unconformable and threatening. He pushes you to the side. The robot should keep more of a distance and find other ways to communicate that it wants to pass.

[11] "This seems quite relaxed." It is a little dumb that the woman needs to wait, but that is the same with someone in a wheelchair, then you also just wait for a moment. The device could have waited for a moment. It would be good if the robot is subordinate to humans, so that he gives humans the priority on the sidewalk. Depending on the speed, but mainly because of the size it is quite intimidating. The device could be a little bit like a dog, they are both subordinate, but the robot should be more predictable. The robot could be like a turtle, but then a little faster. But not as fast as people on skates, because that scares you and makes it more unpredictable.

[5] The KiwiBot looks like a remote-controlled NS train. The upper part looks fine, but the lower part is like a quad, which is cool, but makes it fast and unpredictable. This is probably due to the tires and the mechanical down side. The Piaggio Gita seems fun, as well as the Starship and the PostMates. The last two look calm, everything seems to fit together. The continental looks scary, like a spider. The Segway Loomo looks too much like a driving printer, a vacuum cleaner or a polishing machine.

[6] In the image below, the robots become more positively perceived towards the right. The Piaggio Gita, looks unpredictable. It seems that it needs to balance itself. Predictability is an important factor. The better ranked robots seem friendlier and are relatively small. The PostMates seems cute. It looks like a baby car. The wheels are a little moving outward, which makes it look clumsy, like Bambi. His eyes and colors also make it look friendlier. The Starship looks like a cool, good looking Mars rover. The Segway Loomo doesn't say much about what it is and does and it is boring.

Figure D4. Preference of participant one. The robots become more preferred towards the right.

[7] “I want to feel understood.” He wants to be seen and recognized. I don’t want to feel intimidated, like the PostBot does. I want to know that he understands what I am going to do. But also that I know what he is going to do.
[8] The robot should be reliable. This can be achieved if it looks solidly designed. If the robot looks to be designed with care, it looks more trustworthy. The movement of the Continental will probably by very robot like. The robot should be predictable, transparent and safe. Socially interactive will be important so that it can communicate in an understandable way, in sound and movement.

Participant 2
Male student
[1] The participant has seen a delivery robot in the Netflix series Black Mirror. It was quite big, like a minivan and delivers pizza.
[3] Based on the speed and size, the place in the urban environment could be decided on. They should not be too wide, or go to fast on the sidewalk. A cyclist on the sidewalk could be fine sometimes, except if it is busy. If they are too high, they should go onto the streets, because then they will block everything. You should be able to look over it. On the bicycle lane, the participant would probably cut the device off. Likewise, as a pedestrian. The device has no feeling, so it is fine to cut it off if needed. The participant wouldn’t treat the device as a person, since the device wouldn’t understand you. He would not give priority to the robot, since it is a device, just like a car. If he has priority, he would take it. Sidewalks are made for people, not for robots. Pedestrians have priority over robots, just like they have priority over cyclists. However, the participant says that if the robot gets somewhere first, he is fine with waiting a bit. The robot should take a little bit of initiative sometimes, because the participant would not give priority by himself. The robot has no emotions and will not get irritated if he has to wait for a long time. The interaction is just different, then with people that have emotions and can show where they want to go.
[4] Normal parcel delivery is not always done by people that love their job and they are not always doing the right thing. For instance, not even ringing the bell. They could better get jobs that are more fun. But it is an issue that people lose their jobs.
[2] Money would be the reason. People are expensive and robots don’t need a loan. They are not improving the world, it is just a cost issue.
[9] “This is sad.” The people could have moved to the side. It may signal that it wants to pass. For instance, by talking, visual or a sound. Talking would be weird for the participant, it would be like a ticketing machine that talks to you. If the device talks, then he should also understand what I am saying. He could look in an expecting way. The device (PostBot) feels quite high. You feel blocked, also by your vision. You want to be able to see around you. It is like a concert where you are the large person, but another large person goes stand in front of you. A microphone would be weird, that is a privacy concern. But the same counts for the cameras. The participant wouldn’t buy a Google Home for instance.
[10] The robot touches the pedestrian. That is not comfortable, also not if people do that. He would feel a scare if it is that close. He would think it is broken or wrongly programmed. He would feel negative about the company behind it. The robot may only get into your personal space if he gets invited, just like with people.

[11] This seems like a logical behavior. The robot blocks first and then sees the woman approaching, so that is fine. He is not taking priority, since he is already going. It would be unreasonable to expect the robot to move backwards.
[5] “The continental is here to kill us.” The KiwiBot seems angry. The tires are weird. “Is it going to deliver in the Himalayas?” Its eyes are cute, but his smile is angry. The heart-eyes are shitty. It is childish and it should be a more business-like device. The Piaggio Gita looks like a roller suitcase. The Marble looks like a fridge. It does not seem playful and not suitable for the sidewalk. PostBot is too large. PostMates looks the most fun, good size. It is not too industrial. It is cute, but not too cute. The participant would have most trust in this device. It has a clear front, so makes it easy to see where it is going. It is the right size. It seems reasonable that this device drives over the sidewalk. The Segway Loomo doesn’t look to be able to go outside. The drawers look to be drawn on top of it. The size of the device is important. Too small and you fall over it.
[6] Piaggio Gita seems unpredictable. It could go in all directions. PostMates or PostBot seem the most predictable, but almost all of them are quite predictable, except Continental, Segway Loomo and Piaggio Gita.

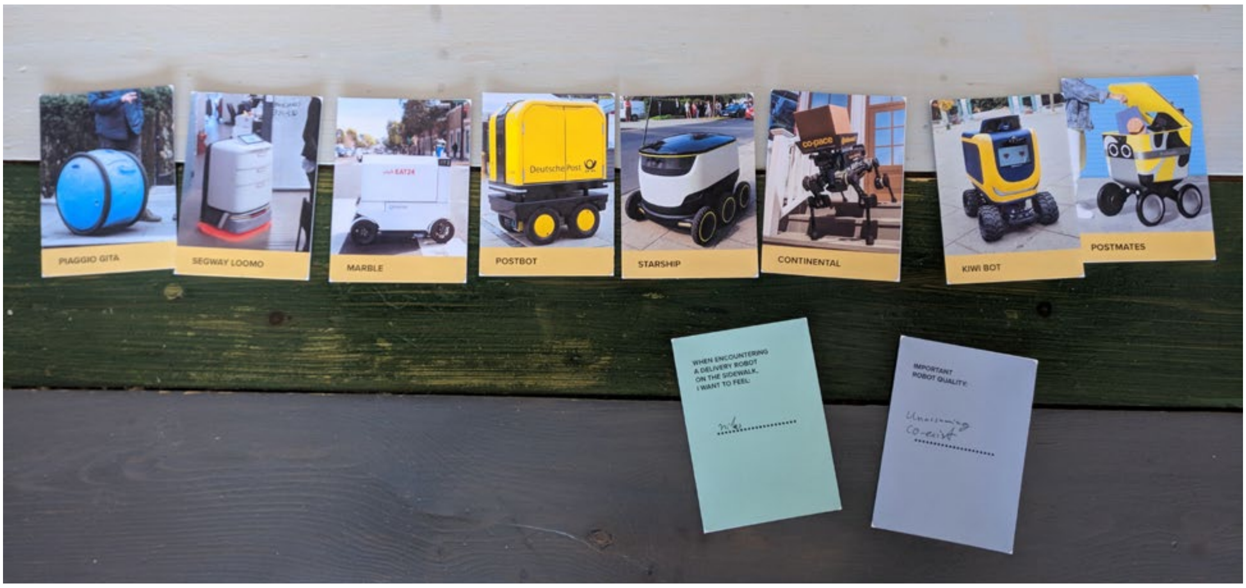


Figure D5. Preference of participant two. The robots become more preferred towards the right.

[7] The participant wants to feel no specific emotion when seeing a delivery robot. Only when receiving a parcel. It is just like encountering an unknown cyclist, or supermarket van.
[8] Not taking up too much space. It should be coexisting with people. To coexist it should not be dominant or have priority. The robot serves the people. The robot could learn when you look angry at it. But more than that to teach a robot is not up to the pedestrian.

Participant 3
Female student
[1] The participant has never seen a delivery robot in real life or on the internet. She expects the robot to be cute. For instance, like Wall-E. Wall-E is mainly cute because of its personality.
[3] Their place in the urban environment is based on the speed. The bicycle lane will probably be the safest and therefore preferred. This gives a more productive feeling. As a pedestrian it is probably annoying to have it on the sidewalk. If the robot touches you, that would be annoying. If the robot goes over the sidewalk, it should go the same speed as people. For parcel delivery this is very slow.
[4] There are some negative aspects. It will become easier to steal parcels. There is also less work for delivery employees.
[2] There are less employees needed. It can also be good for the image of the company, because they are the first one being innovative.
[9] The robot is being ignored. The robot is aware of its surroundings and adapting. The robot should have

a bell which signals that it is coming. It is not possible to always turn around and search for another way.
[10] This situation is better, but dangerous. The robot is coming too close, which could be scary and not really good for privacy. If you know that it is delivery robot, it is less scary. But when you see the device for the first time, it could be scary. It is more annoying if a person comes this close than when a robot does this.
[11] This situation looks fine. The pedestrian needs to wait, but in general it is fine.
[5] Most of them look solid. The PostMates looks like a Stint. The robot should not be too low, because then you don't see it coming and it would be easier to steal. The PostBot looks neat and professional. Your packages will be treated better.
[6] In the figure below, the best robot is positioned on the left, and the least preferred on the right. Decency and professionalism are important. More important than having a face on the robot. The Continental looks like a spider or dog, which is scary. The Segway Loomo looks like it is not able to walk outside, since it looks like a fax-machine or printer. Emotions are not necessary, because you can see that it is a robot. The Starship looks cute, because of the rounded edges and it looks most like Eve from Wall-E. The Marble is not really intimidating, it looks professional. With the PostBot it is not possible to see what the front and the back is.

Figure D6. Preference of participant three. The robots become more preferred towards the left

[7] It is important to feel safe. You don't want to be hit.
[8] The device should be aware of its surroundings. You see that it has sensors that map the environment. The device should know when it should give priority to pedestrians. The movements should be empathetic. In general, the robot should be neutral, not a specific gender, or aggressive.

Participant 4
Female adult
[1] The participant has never seen a delivery robot in real life or on internet. It could be something like a vacuum cleaner robot with a package on top.
[3] They are probably small, so on the road would be dangerous. So, it will probably drive over the sidewalk. It should not be in the way of people. You will probably have to move aside, just like a baby stroller. A robot on the sidewalk could feel irritating on the sidewalk. So on the bicycle lane would be better. If it drives over the sidewalk, it should go slower when it approaches people. This is to not scare people.
[4] Normal parcel delivery employees are always in a hurry, they are driving dangerously and not environmentally friendly.
[2] It is probably cheaper than an employee.
[9] Going back is not always an option, because a detour would take too much time. The device could have a bicycle bell. For a baby stroller you move aside, so the people could also move aside. Talking could be even better. A bicycle bell could be intrusive.
[10] The robot shouldn't come this close, that is uncomfortable. He should have asked a little earlier if he could pass.

[11] This looks decent. It almost comes to close to the passive person. He is not paying attention. The other woman sees it coming, so then it is fine if the device comes a little closer. The walking person has priority, but it is critical because he probably couldn't see it.
[5] The first question in the head of the participant is: How do you get your package from the device? The package on the continental can be stolen. It doesn't seem that the Piaggio Gita has much space for parcels inside. It looks weird but modern. The Segway Loomo seems weird to encounter, since it doesn't look like a package delivery. Starship, Marble, KiwiBot, PostBot and the PostMates are fine to encounter. The Continental looks like it a walk stairs. It really looks like a robot, which could be nice. But it appeals less. The Starship has a very clean design. On the sidewalk, a delivery robot may not be too small. Because then there is no space for packages and it is easier to fall over it. It may also be not higher than your chest, because you want to look over it. A little higher than your waist.
[6] On the top left is the most preferred and, on the bottom right, the least preferred.
PostMates really seems like a device for now. It looks like a shopping cart. You can imagine that it is driving. But since it is a new device it doesn't have to look like anything. Starship looks way nicer, but is too low. The Marble has a good size, is probably functional, but is not beautiful. There is nothing wrong with the KiwiBot. His eyes are not really obvious. But also the PostMates has no obvious eyes. Eyes are funny, but it is not necessary. PostBot is almost a truck, so it should not drive over the sidewalk. If the participant would walk over the sidewalk and encounters the PostBot, she would hope that the he has seen her and that he will not hit her.

Figure D7. Preference of participant four. The robots become more preferred towards the top left. Least preferred on bottom right.

[7] You don't want to feel a threat. You want to feel safe.
[8] You look at the robot as a device, but eyes give a sense that they see you. The Starship also looks like it is having a beam with cameras. With the Piaggio Gita you don't see that it is looking. The movement should be fluent. Not rigid, because that gives a negative feeling. With the Starship you expect it to talk. The PostMates as well, which is because of the eyes. The eyes give it something human. The conversation will be something like: "Can I pass?"; "Take the package." It would be nice if it understands talking back to the it. Because otherwise, you don't have to talk to it anymore, or can just say negative things about it. The participant doesn't expect any of the robots to talk about the weather. No one will probably have the need to talk about the weather with a robot. The robot is not personal and will never be that. The PostBot, Piaggio Gita and Marble probably don't talk.

Participant 5
Male adult
[1] The participant has never seen a delivery robot. Only on the internet a delivery drone.
[3] The participant expects that the robot will drive both on the street and the sidewalk. The street is more streamlined. A robot on the sidewalk would take some time to get used to. It will be hard for the robot, but technology is able to do a lot. The first reaction when seeing a delivery robot will be: “Will it go aside for me?” The technology is probably made to do this. The device is not human, so there is less acceptance if something goes wrong. If you hit another person, you accept that the other made a mistake.
[4] The impact of the robot is good. It is probably faster than a van with a lot of packages. It is also good that there are less vans on the road. For companies it is also good, because you are more sure that what you order gets delivered: there is more trust.
[2] The cost price of the service is lower, because of labour cost reduction.
[9] The robot should “break” the blockage. He should lay contact with the pedestrians. The robot is not able to know what the people are talking about. This could be very serious, like talking about a relative that died. You don’t want the robot to interfere that. So, the robot should know how to interfere in different situations.
[10] The behavior of the robot is intrusive. The robot is coming in the personal space. He should lay the contact earlier. Being the person in the video would not be nice. For the image of the company it is not good if situations are handled wrongly. But that is similar with current delivery vans.
[11] This is within the limits of acceptability. The person needs to wait a little, but the robot also has some right on the sidewalk. If the robot had seen the pedestrian, he could have waited, but in general this is all fine.
[5] The Segway Loomo looks like a rolling printer. The participant likes to see colors, because it is joyful and draws attention. The Piaggio Gita, still needs to prove itself, but it seems maneuverable. For the robot that would be good, but as pedestrian it will not look like a calm movement. Calmness on the sidewalk is important. Too rough behaviors will also not be good for elderly people.
[6] In the image below, the image on the left is leased preferred, on the right the most preferred. Formgiving is important. A driving printer like the Segway Loomo will not improve the world. The Piaggio Gita might not be kind enough on the sidewalk. The Continental looks too much like a robot. The PostBot has a nice color, it looks solid, but it is too business-like. A little bit of fun, like with the KiwiBot would be good. The Starship looks really good, it looks a little bit robot-like, but doesn’t have enough color. The PostMates gives you joy, especially when it delivers your parcel. It would be nice to have a little bit of personality in the device, because that makes it more personal. The PostBot looks too large. However, it will be good for carrying parcels. If the robot is lower than your knee, it will be too short. It may reach above the middle of your upper leg, since it is more obvious to see. The Segway Loomo looks too much like a business device, which is not joyful. The eyes are quite nice. You can also see a little bit of those eyes in the Starship. Eyes give it some personality.

Figure D8. Preference of participant five. The robots become more preferred towards the right.

[7] You want to feel equal to the robot, since you are both on the sidewalk. Another emotion is joy or pleasure. But on the other hand, you don’t need to feel anything.
[8] The robot should not go faster than you. It should be equal. Size is important for being equal.

Participant 6
Female adult
[1] The participant has never seen a delivery robot. She expects the robot to be cute and human-like. You know it is a robot, so it does not need to talk. But it should understand what people say and give acknowledgment. The robot could help me with bringing a heavy parcel inside.
[3] Depending on the speed and the ability to avoid people, its position in urban environment should be decided. Sidewalk would be fine, if it gives priority to people and does not endanger them.
[4] Contact with people is important, so the current delivery vans are fine.
[2] A robot could deliver more services, so more specific delivery time-frames and it could work in the evening. Delivery on time is very important, especially for things you really need.
[9] The robot could signal the people and the people could step aside. The robot has the right to pass. It is subordinate to people, but if law says that the robot is allowed to drive there, then people should let him pass. The robot could have talked to the people, like what happens on Schiphol with “Mind your step.”
[10] If a robot is touching a person it will be very unpolite. It should have signaled the people earlier.
[11] This situation is not really right. Dutch people use silent agreements and rules to walk. It is somewhat similar to driving a car. The robot should have waited for the pedestrian. You expect the robot to behave just like people. People don’t want to learn logics. In countries like China, people go faster to take priority over other people, they don’t have any patience. In Japan people are really decent, they will wait for a red light, when there is no one around.
[5] The PostBot looks very German, very decent. The Starship looks like it could have a solar panel on top, just like the Nuon Solar car. If the Continental walks by, it will draw attention.
[6] Cuteness and appearance are important. It could be a tourist attraction. As a pedestrian it should be calm, not loud, easy to open, not too large. The size of the PostBot is fine. You can see it through your window when you are in your house. If it is very small, you can’t see it and it has not enough space for packages. The PostMates looks like a baby stroller. It is important to keep parcels separate, you don’t want your package to be stolen. The way of unloading is also important. Elderly don’t want to take the parcel from the top. The safety of a robot could be higher than with delivery persons. Especially in China, people don’t appreciate people coming to their door.

Figure D9. Preference of participant six. The robots become more preferred towards the right.

[7] Humor would be good. Just like Coolblue is doing.
[8] The design should be modern. Eyes are fun.

Participant 7
Senior woman. Results were documented based on notes taken during the session.
[1] The participant has never seen a delivery robot in real life. Since she is not active on the internet, she has not seen it there either.

[2] Delivery robots are probably precise and quick in what they do.
[3] They will probably drive over the sidewalk, however they might be quite wide for the sidewalk.
[4] This technology would be fine, but in places such as parks they might not fit. That are places where you go for a calm walk.
[5] The Startship robot appeals to the participant. How it is shaped is appealing. The Kiwi robots' wheels are way too rough. The PostBot is too rough as well. "What is that for a thing? I can't place it. What is it going to do?" If the participant would see the PostBot on the sidewalk, she would take a step/jump aside. The PostBot raises the question how it is moving around. The device raises too much questions, so there isn't much trust in the device.
Robots with eyes are playful, they look fine.
[6] In figure D10 the least preferred robot to encounter on the sidewalk is positioned on the right, going to more preferred on the left.
[7] The emotion surprise was chosen. The participant interpreted the question as what emotion would I feel if I would encounter a delivery robot. The participant chose for surprise because she would be amazed about the development we are going through. She would definitely not feel scared when encountering a robot on the sidewalk.

Figure D10. Preference of participant seven. The robots become more preferred towards the left.

[8] A talking robot would be scary. The robots are somehow looking like people. Not specifically for their shape, but more for the function that they have. They perform tasks that people normally do. Shape wise, the continental robot looks the most like a human. This technical look feels less pleasant.
[9] People should give the robot some space. Maybe he could make some sound. A bicycle can also make sound with a bell.
[10] The robot shouldn't touch the person. A person might react aggressive. If the participant would be the person on the right, she would feel unsafe and probably be a bit scared. She trusts that the robot won't be aggressive, but the robot might run into people.
[11] The opposing person should be so kind to wait for the robot. That person could even better move to the side so the robot can go through easier. But on the other hand, the robot should have seen the person approaching and wait.

Participant 8
Senior man
[1] The participant has never seen a delivery robot in real life. From trade magazines he got some ideas about delivery drones, but has never encountered a delivery robot.
[2] Efficiency will be the main driver for business to save money and therefore a reason why companies are interested in delivery robots.
[3] In places like hospitals, the participant could visualize what the position of the robot would be. But for a delivery robot it is hard to visualize what its position will be in the urban environment.
[4] "If I would encounter the robot in real life, I would want to know what it is all about." The participant would be curious about it, but definitely not scared.
With a lot of robots, you get a cold society. You can't talk to it like you do with normal people. They might say good day to you. Robots should be public friendly, so they shouldn't only post parcels, but they should

also react human friendly to pedestrians. If there is a DHL employee at the door, the participant sometimes makes a quick talk. But they might, just as the robot, also don't have time for a talk.
[5] The PostMates looks like a bucket, a little bit like a Stint. "Such a thing on the pavement, could be a significant obstacle." If a lot of companies implement them, it might become too much. But you probably get used to them. You already see quite some new electronic devices on the street and that is fine, but if it becomes too much of them, then it gets a problem. It is hard to visualize how it would look like if there are a lot of them. Drones are outside of your personal environment, but a delivery robot is.
[6] Unfortunately there is no picture of the order of preference in which the participant put the existing robots. All of the devices are in the negative spectrum, from most negative to least negative. The PostMates looks like a child wagon. The Continental robot looks like something coming from Starwars. The Segway Loomo looks like something from an office interior, so this one is one of the least preferred. The PostBot seems a bit too large. If it is one of them, it would be fine, but a lot of them not.
[7] The participant responded to the question with an emotion which he expects to feel when encountering delivery robots. He chooses for "wonderment". The participant would be interested. He only has this interest in device in which he can see what it is. So, for instance with the Piaggio Gita, it is not really clear what it is and how it moves, so there is a lower level of interest. If it looks nice, then he wants to know what it is and what it does. He would definitely not feel scared or irritated.
[8] This is a hard question. If the device walks or moves over the pavement, it should be able to communicate, for instance when it moves into you. Off course the device should be safe. If it looks robot-like or human-like is not really relevant. The robot should anticipate on what happens in its surroundings, that is what you expect from it.
[9] If the robot always goes back when encountering obstacles, it will probably never reach its destination. In this situation it would be good if the robot could communicate with the people. For instance, if it talks to you: "Can I please move through."
[10] If the thing doesn't have said something, then the man getting touched would probably not have liked it. The participant would probably call the production company to tell that the "person" is not really a good thing. At this instance the participant said person instead of device or robot. He explains that he still only thinks in the way of humans and not in robots. The participant wouldn't like the device to be like a clone. It can still stay like a robot, but one that can communicate with its environment just like a human can.
[11] The robot cleanly maneuvers around the passive pedestrian. The participant didn't notice that the opposing pedestrian needed to wait for the robot. After explaining this, he says that people are different. Some of them will calmly wait, others will walk through. If there would be a collision he expects that there is a possibility to communicate with a human.

Participant 9
Senior woman
[1] The participant has never seen a delivery robot, so has no experience with it. She says that this might be the reason why she has a negative attitude against them.
[2] Everything becomes very impersonal. All social media, with its technicalities make that there is way less communication. The participant expects that the robot rings the bell. The participant thinks that you get handed over your package from a dead thing. You don't have to say thank you to it, so she would probably not do that. But you should actually do it, because it brings the package to you. If the device would talk, the participant would talk back but doesn't expect it to be a very good conversation. It is a different conversation than with a person.
[3] Since the devices are probably slow, they will likely drive on the sidewalk. But since they could be wide, that would be unfortunate. As a pedestrian you should always look out for not being hit. If a robot approaches, the participant would be more careful and maybe step aside.
[4] The participant prefers the current situation over the implementation of the technology. She expects that the technical improvement will continue, so as a person you should adapt to it.
[5] They look like monsters. Continental looks most like a monster.
[6] The least preferred robot is positioned on the left, the most preferred on the right, in the figure below. The participant rated robots with more capacity as more preferred. "Robots with eyes might see me as well". The participant is not sure if the robots can see her, or if the person controlling the robot can see her. After explaining that the robots see with a camera and make decisions on their own, she concludes that she does not have to move out of the way, the robot will move out of the way. The Piaggio Gita is not really understandable. It is not clear how it moves.
[7] Irritation would be the emotion that the participant would experience.
[8] This emotion is coming from the impersonal aspect. The participant would give the robot some space,

because the sidewalk is not really wide. “The robot should not drive with high speed into the door opening if I open it”. If the robot says: “I have a package for you”, that might sound sympathetic. She might appreciate it, but it is not really necessary. After seeing the card with “predictable”, the participant says that if a lot of robots would be implemented, it will get less predictable. The participant would appreciate it if the robots are all the same and predictable. She is mainly concerned with how they work when you have ordered a package. So, the lid should be similar for instance.

Figure D11. Preference of participant nine. The robots become more preferred towards the right.

[9] ”Does the device make sound when it approaches?” The participant thinks it should do so, otherwise it is not able to pass. It would be convenient if it has a bicycle bell. The people in the video should move to the side. If this technology is implemented, you don’t hold it back, so you can better work with it.
[10] The robot seems to touch the person. The robot should not bump into people.
[11] This is a stupid situation. The woman should step aside if the robot approaches. The woman has seen both the man and woman, so it could have moved to the left. After explaining to the participant that the robot could also have waited for the woman, she says that for such small things, you shouldn’t make problems about it.

Ranking the robots
The ranking of the robots can be seen in figure D12 and D13. The best scoring robots, based on these eight participants, is the Starship robot. For seven participants it was the preferred or second preferred robot. For one person it scored significantly lower. In close proximity is the PostMates robot. It was the preferred robot for three participants. The other five participants ranked the robot in the middle category, namely a score of 3 till 6. The Starship and the PostMates are clearly the two favorite robots. The other five score at least 13 points lower than the PostMates. The Continental robot was ranked the lowest.

ROBOT/PARTICIPANT	#1	#2	#3	#4	#5	#6	#7	#8	#9	TOTAL
Continental	1	6	1	3	4	5	2	x	1	23
Piaggio Gita	6	1	2	2	3	7	4	x	2	27
Starship	7	8	8	8	7	8	8	x	3	54
Marble	4	3	6	7	2	1	7	x	4	34
PostBot	3	4	7	4	5	2	1	x	7	33
PostMates	8	8	5	6	8	3	5	x	6	49
Segway Loomo	5	2	3	1	1	6	6	x	8	32
Kiwi Bot	2	7	4	5	6	4	3	x	5	36

Figure D12. Scores of the robots based on 8 participants. A score of 8 is the preferred robot, 1 the least preferred.

Figure D13. The total score of the robots.

PARTICIPANT	PREFERRED EMOTION	ROBOT CHARACTERISTIC
1	Feel understood	Predictable, not intimidating
2	Nothing	Not to large, coexisting, subordinate
3	Safe	Aware, visible sensors, empathic movement, know when to give priority
4	Safe	Fluent movement, eyes to give sense that it sees you
5	Joy / nothing	Be equal, same speed, not too large
6	Joy / humor	Same marketing as Coolblue
7	Surprise (expected instead of preferred)	Because of the tech development
8	Wonder (expected instead of preferred)	Only if the robot is recognizable
9	Irritation (expected instead of preferred)	The robot creates an impersonal society

Figure D14. Preferred emotions by the participants and the important robot characteristics.

Discussion

None of the participants has ever seen a delivery robot in real life. Therefore, they form an image in their head based on their own perspective. It is in general hard to imagine something that you never seen before. The videos with robot-pedestrian scenarios were really helpful to visualize the robot in a real situation. However, the participants saw a situation with 3 other people. Their opinions might change if they are by themselves part of the interaction. They could be in a certain state of mind or having a goal to accomplish, that makes them less acceptant to a robot on the sidewalk. Therefore, further testing should be done with a more immersive way of testing, like with a moving physical robot or a virtual environment.

The interview was a qualitative research. The robots were ranked based on eight participants, because for one of the participants the results were not preserved. This ranking gives some insight in what people think about these robots, but is a too small of a group to retrieve final conclusions from them. Also, the ranking is from worst to best. The best robot could still be not preferred by the participant, as some participants mentioned.

Conclusion

In general the level of acceptance of the participants seems positive. Some of them would be curious when encountering a robot. None of the participants would be scared. However, this is depending on the behavior, since some mentioned that they would be scared if the robot would come really close, like in scenario 2 of the pedestrian-robot interactions. There was one senior participant who was very negative about the delivery robots, because more robots make the world more unpersonal. But in general, some participants saw advantages of the robot over delivery vans. These vans are seen as dangerous, since they drive fast. Some concerns that they raised, like the theft risk of parcels and the lack of human interaction might be solved by design.

The robots were often seen as subordinate to people. However, when showing the videos about the pedestrian-robot scenarios, there was the convincing opinion by all participants that the robot has some rights on the sidewalk. When they get implemented and are allowed by law, they also have the right to "ask" people to move aside, when they are blocking the sidewalk. The robot is doing its job and has the right to do so, even if people have to adapt a little. The solution of a bicycle bell was mentioned multiple times. Also in a the situation where the robot was overtaking a person, but blocked another person for a few seconds, this was seen as a fine interaction, since the robot was first. In can be concluded that the rights the robot has are approaching the human rights. However, it should not expect to get priority from people. The robot might need some assertiveness to utilize its rights. It also seems likely that some pedestrians will challenge him and might cut them off.

The participants had strong opinions about the size of the robot. The robot should not be too high, since it will block your vision when walking on the sidewalk. Most adults should be able to look over the device and still have a good sight on their environment. On the other hand, the robot should not be too low. A size similar to the Starship seems too low, which makes it easier to be overlooked and enlarges the risk of falling over the robot. The ideal size should be determined later.

Participants seemed to value usefulness of the robot. Especially on a practical level, they had opinions about appearance and how to use the robot. Rectangular shapes seemed more logical to something that delivers parcels. Very round shapes were therefore not preferred. It seems that the participants preferred robots that clearly communicate what their function is and how it works. They were also concerned with functional elements that relate to being a customer, like theft risk of parcels, ways to unload parcels and about how to know if the robot arrived to your door. During the design process of the delivery robot, these functional elements should also be addressed to maximize acceptance by pedestrians. A point which will not be addressed, but might have an influence on the perceived usefulness is the speed of the device. One participant addressed that the sidewalk seems slow and unproductive. A device that drives over the bicycle lane or is a hybrid device that can both use the bicycle lane and the sidewalk, might seem more useful for people.

The appearance of the robot seems to be seen remarkably much in relation with products that the participants already know. They associate the form with for instance shopping carts, baby strollers, printers, dogs and fridges. It is not clear what the effect is of these associations. For the Kiwi Bot it was negative. It looks like a remote-controlled toy, which makes it look unpredictable in its movement. For the Segway Loomo it was also negative. Its printer-like shape didn't make it look useful. For the Marble and the PostMates, the associations were not clearly negative or positive. Since there was no robot where the association had a positive effect, it can not be concluded that positive association is a good design goal. Products that don't have much associations, such as the Starship can also be highly preferred.

Since the Starship ranked the highest, it could be possible that the amount of humanness that people want in a robot is quite low. The device has a distinct area for the sensors, which gives it an impression of a face. But furthermore, it doesn't have much anthropomorphic elements. However, the second best ranked robot, the PostMates, has more clear anthropomorphic elements, namely the eyes. A more precise level of humanness will need to be decided in further research. The fact that these two robots, and especially the Starship, are preferred, also indicates the importance of a good design. It is not clear how this influences preferences, but it could be because products that are seem to have a very thought out design, might also have a very thought out behavior and are therefore more trustworthy or useful.

Indicator and gesture user test
Appendix E

Goal of the user test
Two ways in which the robot can show his intentions (intent indicators) were designed. The first one is a led bar which is a more mechanical way of showing intentions. The second indicator is more human like and uses eyes which look into the direction that it will go. In this study, their effectiveness will be tested in establishing comfortable pedestrian-robot interactions. There might also be other cues that pedestrians are looking for in the robot that indicate intentions. They might be visible in the scenarios or missing in this simulation. By understanding at what characteristics people look at in the robot, there could be more emphasize on these elements in the design.

The second focus of the study is to test how posture gestures will influence the interaction between the pedestrian and robot. With posture gestures, pedestrians can show their intentions and therefore create a clear cue on which the robot can react. An example can be movements with the arm to indicate that the pedestrian will go in that direction. The goal is to see how this influences the interaction and if and what gestures are comfortable and acceptable to perform by the pedestrian.

Research questions
- For what robot cues or characteristics do pedestrians look in order for them to have a comfortable crossing with the robot?
- What is the influence of intent indicators on the crossing interaction between pedestrian and delivery robot?
- How well are the two designed intent indicators perceived and understood?
- How do posture gestures influence the crossing interaction between pedestrian and delivery robot?
- What posture gestures do pedestrians think will yield good pedestrian-robot interactions that will help them to cross each other comfortably?

Test setup
During the study the participants will be brought into a virtual environment of an urban area, through the use of an HTC Vive VR headset. The participant acts as a pedestrian and interacts with an approaching delivery robot. The participants will physically walk for approximately 3,5 meters. The test consists of three different versions of the intent indicators, with each a scenario in which the robot stops, a scenario where the robot turns right around the block and a scenario in which the robot reacts on a gesture input from the participant.

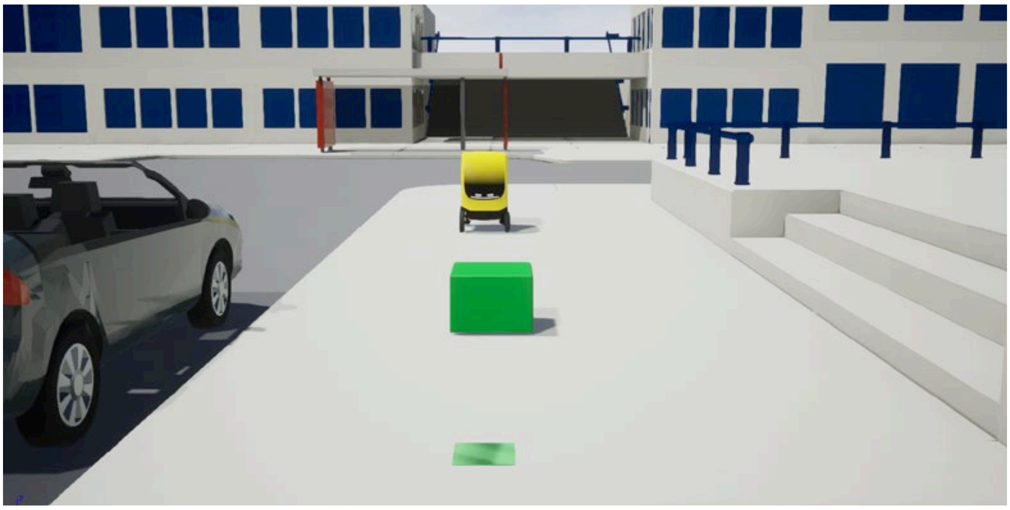


Figure E1. View of the participant at the beginning of each scenario.

In all scenarios the participants start walking over the sidewalk in the direction of the robot. A block/bench is located in the middle of the sidewalk to establish a fixed point of interaction between the pedestrian and the robot. In scenarios N1, N2, L1, L2, E1 and E2 the robot does either stop or pass the block on the right side (seen from the pedestrian). The robot has a fixed path and does not adjust its decision based on the behavior of the participant. This simulates a possible real-life scenario, in which the robot is not able to predict if the pedestrian will pass him on the left or right side and resolves the situation by taking initiative in choosing a direction. The robot first gives an indication of its intents and then performing the movement.

The behavior of the robot in scenarios N3, L3 and E3 is depending on a possible input from the participant. With the HTC Vive controllers the participant can make posture gestures to interact with the robot and therefore determine how the crossing will take place. If the participant points to the left or right, the robot will take the other side of the block. If the participant decides not to perform a gesture, the robot

SCENARIO	INTENT INDICATOR	BEHAVIOR
N1	None	Stop
N2	None	Turn right
N3	None	Interact or turn right
L1	Blinking led bar	Stop
L2	Blinking led bar	Turn right
L3	Blinking led bar	Interact or turn right
E1	Moving eyes	Stop
E2	Moving eyes	Turn right
E3	Moving eyes	Interact or turn right

Figure E2. Overview of the different scenarios tested.

Before the test
The participant is asked to sign a consent form, which describes that the data will be kept anonymous and that he is entitled to stop the study at any time without giving any reasons. He also answers some basic questions of a preliminary questionnaire:

Please fill out this preliminary questionnaire, it helps to classify the experiment data.

Age	18-25	25-30	30-35	35-40	40-45	45-50	over 50
Gender	male	female	prefer not to answer				

How much experience do you have with virtual reality?

None						Expert
1	2	3	4	5	6	7
O	O	O	O	O	O	O

How confident do you feel about being in a virtual environment?

No confidence						Very confident
1	2	3	4	5	6	7
O	O	O	O	O	O	O

During the introduction, the participant is brought into the virtual environment to get accustomed. He can explore the area to feel that it is safe to walk. The participant will be asked to start every scenario on a marked spot on the ground and start walking towards the robot when the block in the middle of the sidewalk turns green.

Scenario N1, N2, L1, L2, E1, E2.
The scenarios with a number 1 and 2 are tested in a random order. After each scenario the participant is asked to answer some questions to what extend they agree with some statements about the interaction with the robot:

- Which robot cues/characteristics helped you with choosing a side to go to?

Strongly disagree			Neutral			Strongly agree

- I was concentrated on a wide variety of things in the environment.

Strongly disagree			Neutral			Strongly agree

- My decision was based on the robot's behavior.

Strongly disagree			Neutral			Strongly agree

- What animation did you see on the front of the robot and what do you think it means?

....

- The animations of the eyes/led bar was clearly visible. (skip if there is no intent indicator)

Strongly disagree			Neutral			Strongly agree

- The robot communicated clearly that it was about to stop/turn. (Why?)

Strongly disagree			Neutral			Strongly agree

- The interaction with the robot felt comfortable.

Strongly disagree			Neutral			Strongly agree

Scenario N3, L3, E3
The scenarios with a number 3 are tested in a random order. Before testing the participant is explained that he can use a gesture with his hand, arm or posture, to communicate with the robot who is going left and who is going right. He can use a gesture that feels natural and intuitive to interact with the robot. In these wordings the specific gesture and the meaning of that gesture is up to the participant. After each scenario the participant is asked to answer some questions and rate the interaction with the robot:

- Which robot cues/characteristics helped you with choosing a side to go to?

Strongly disagree			Neutral			Strongly agree

- I was concentrated on a wide variety of things in the environment.

Strongly disagree			Neutral			Strongly agree

- My decision was based on the robot’s behavior.

Strongly disagree			Neutral			Strongly agree

- What animation did you see on the front of the robot and what do you think it means?

  ....

- The animations of the eyes/led bar was clearly visible. (skip if there is no intent indicator)

Strongly disagree			Neutral			Strongly agree

- The robot communicated clearly that it was about to stop/turn. (Why?)

Strongly disagree			Neutral			Strongly agree

- Using a gesture felt as a natural way of interacting with the robot.

Strongly disagree			Neutral			Strongly agree

- Why did you use this gesture to interact with the robot?

  ....

- The robot reacted as expected on my gesture?

Strongly disagree			Neutral			Strongly agree

- The interaction with the robot felt comfortable.

Strongly disagree			Neutral			Strongly agree

After all scenarios

The study ends with some general questions to confirm the preference of the participant and to give the opportunity to speak openly about the robot. There are also some questions to test if the situations were in general complicated and how they were experienced:

- How human does the robot without indicators feel? From machine-like to human-like.

Strongly disagree			Neutral			Strongly agree

- How human does the robot with the led bar feel? From machine-like to human-like.

Strongly disagree			Neutral			Strongly agree

- How human does the robot with the eyes feel? From machine-like to human-like.

Strongly disagree			Neutral			Strongly agree

- The situation feels unstable and feels likely to change suddenly.

Strongly disagree			Neutral			Strongly agree

- The situation feels complicated.

Strongly disagree			Neutral			Strongly agree

- I felt highly alert during the situations.

Strongly disagree			Neutral			Strongly agree

- The situations felt familiar.

Strongly disagree			Neutral			Strongly agree

- What characteristics of the robot helped you with deciding which side you choose? (multiple possible)
  - The gazing eyes
  - The blinking bar
  - The path of the robot
  - Small movements of the body when turning or (de)accelerating
  - The robot starts to brake
  - The robot starts to turn
  - Other..........................

- Are there characteristics that you expect the robot to have, but were not visible in the visualization?

  ....

- Which robot communicated the best what it is about to do?

  ....

- Would the gestures that you performed be something that you see yourself doing when interacting with sidewalk robots? Why, why not?

  ....

- Would you accept robots like this to operate on the sidewalk?

  ....

- Which robot would you prefer?

  ....

- What do you think about the size of the robot?

  ....

- What do you think about how the robot looks?

  ....

- Are there other things you would like to mention about the robots or the test?

  ....

Results

In the table in figure E3, the average score per scenario can be seen on the different Likert scale questions. The scores for the visibility of the indicator, the clear communication of intent and the perceived comfort, are also mapped in figure E4. The scores about the devision of concentration, don't point to a difference between the different scenarios. Two participants indicated that in the scenarios with the gesture interactions, there was more focus on things like the final destination, other objects in the environment and your own path. However, this is not coming through in the scores. In general the score is low, indicating that participants were mainly looking at the robot and its indicators.

The participants rated the extend to which their behavior is based on the behavior of the robot, lower with the scenarios with gesture interaction. In these cases they are more inclined to make a decision by themselves, without looking at the robot. With the led bar, which is seen as a clear intent indicator, the participants base their behavior relatively more on the robot than with the other two robot variants.

The eyes that look into the turning direction, was not seen as a well visible animation. Participants often didn't see any change in the eyes, or didn't see the transition of the animation. This is both for the stopping and the turning animation. Since the indicator has a significant role in clearly communicating intent, he robot with the eyes therefore scored bad in this area. This can be explained by both the visibility as the understandability of the indication.

The robot with the led bar blinks with an orange light into the turning direction. This was rated as highly visible and also clearly communicating intent. The bar getting narrower when braking was less visible and even less good in communicating the robots intentions.

	Broad concentration	Based on robot	Natural gesture	As expected	Visibility	Clear intent	Comfort
Scenario 1 (blank, stop)	2,4	3,9				1,7	3,7
Scenario 2 (blank, turn)	2,7	5,3				2,4	3,1
Scenario 3 (blank, interact)	2,4	2,9	4	3,8		2,2	3,6
Scenario 4 (led, stop)	2,6	5,4			4,1	3,6	4,3
Scenario 5 (led, turn)	2,9	6,1			5,6	5,4	5,2
Scenario 6 (led, interact)	2,5	4,2	5	4,6	5,5	5,5	4,8
Scenario 7 (eyes, stop)	2,9	5,3			2,8	2,2	5,4
Scenario 8 (eyes, turn)	2,8	5,7			2,9	2	3,7
Scenario 9 (eyes, interact)	2,4	2,9	5,5	5,4	2,9	3,4	4,3

Figure E3. Table of average scores, per scenario.

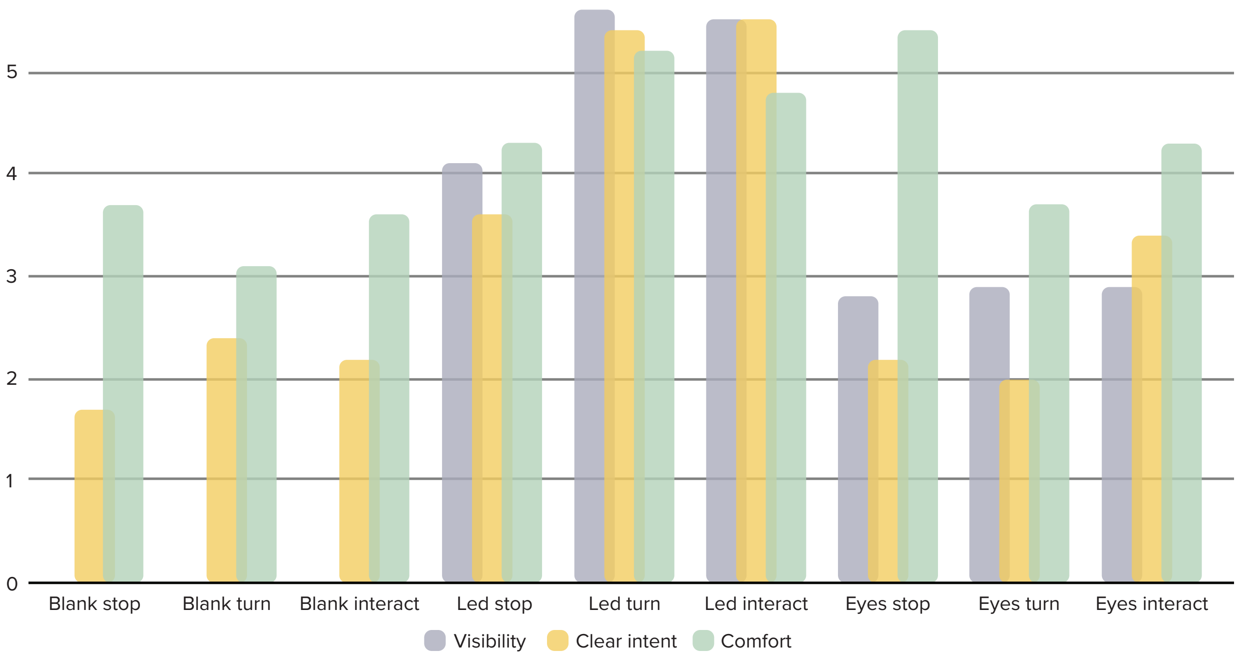


Figure E4. Graph of the quality of interaction for every scenario.

In scenario 7 (eyes, stop) the comfort of the interaction is rated relatively high compared to the quality of the indicator. This can be explained by the relatively large differentiation of the robots path. The robot held strongly left, which made it easy for participants to walk freely to the other direction.

	Humanness
Robot No indicator	1,6
Robot Led bar	5,4
Robot Eyes	4,8

Figure E5. Average perceived humanness

	Helpful for # participants
Led bar	10
Eyes	4
Path	9
Small movements	2
Start braking	2
Start turning	7

Figure E6. Helpful characteristics to make a path decision.

In figure E5, the average perceived humanness can be seen for each of the three robots. The robot without indicator, is perceived as very machine-like. The other robots are perceived as more human. The robot with the led bar, which is perceived as a mouth, the most. The mouth is a strong human element that gives the robot a more friendly appearance.

In figure E6, the characteristics of the robot can be seen and how much participants found them useful for making a decision which side to go to. All participants agreed that the led bar helped them, compared to only 4 participants for the eyes. Nine participants ranked the path of the robot as a helpful characteristic. Interestingly, the starting of turning was a helpful characteristic, but the starting of braking was only seen twice as helpful.

Discussion

Testing in virtual reality will have an influence on the outcomes of the test. The benefit of using VR is that it is feasible to test the visual design of the product, different variations and the behavior. This would not have been possible with physical prototypes within the available resources. However, it still is a simulation of reality. Some participants indicated that they felt submerged in the simulation, but it inevitable that for instance dangers are experienced differently. If the robot moves right at you or even comes very close, this feels less dangerous than in real life. The level of submersion in the environment is also depending on how much you are still connected to the real world. If you are afraid to walk into real world objects, you will take a more cautious way of walking and might concentrate less on the virtual environment.

There was a wire-frame visible to indicate what the safe area of walking is. This available space is small, so after a few steps of walking you already need to stop, so only part of the crossing interaction is done.
The hardware also has its limitations. The pixel density is low, so it is not possible to clearly see the intent indicators from far away. If the indicator was ranked as not clearly visible, it could therefore be the indicator itself, or due to the hardware limitations. Another limitation of current technology is the stability of the view within the headset. Sometimes, and especially when looking down, the view sometimes got distorted. This is a really unpleasant experience which makes you feel unstable.

The virtual environment and robot were not optimized to be visually appealing, for instance by applying textures on the materials. It is expected that this has only a minor influence on the experience, since the physical shape is already enough. A too visually detailed model might skew the results, since participants are then more inclined to answer positively.

The functioning of the model, like how the robot moves, is more important. To lower the development time, it was chosen to make the robot follow the same path every time, without reacting to the participant (except for the three interaction scenarios). Therefore, it is not able to solve unexpected situations. Since the model is slightly depending on the processing power of the computer, small deviations can occur between the scenarios and from participant to participant. For example, when the robot approaches the block, it might go more to one side, giving the impression that it will turn to that side as well. Participants are inclined to use this cue to make a decision about their own path, over the intent indicator, which is the parameter which should be tested.

Participants were more inclined to go left from the obstacle. This was due to the robot either stopping or going right (from the view of the participant). Also the bus stop, which was positioned slightly to the left, had an influence.

For the question about how natural the gesture interaction felt, participants were asked to rate the gesture that they previously performed. This includes normal walking behavior, without performing a dedicated gesture like a hand wave. Hand gestures were often seen unnatural, while normal walking behavior was seen as highly natural. Therefore, the scores are not accurately representing the question.

If the behavior of the robot was as expected, is depending on the gesture that they did. If participants communicated their walking direction, than the robot reacted mostly as expected. But if their was a gesture in the direction where the robot should go, than the robot might react unexpectedly. Another inconsistency is that timing is very important in the interaction. If participants were too late with the gesture, the robot already turned to one side. All the inconsistencies together make this question not an accurate description of the quality of the interaction.

The animation of the eyes was poorly visible, which will also influence the rating of the clearness of the robots intent. There can only be looked at the participants who saw the indication to find results for the understandability.

Conclusion

For what robot cues or characteristics do pedestrians look in order for them to have a comfortable crossing with the robot?

The test showed that an increase in clear intent communication improves the perceived comfort by the pedestrian. The robot with the led bar clearly communicated its intentions and had a high perceived comfort. Some participants also brought forward that the turning of the wheels is a cue that the robot is changing its path. The last important indicator is the path that the robot is taking and the position on the sidewalk. In the scenario in which the robot clearly held itself to one side, the interaction was perceived as highly comfortable, while the indicators had a low score on visibility and understandability. Communicating intentions by the robots trajectory might be the strongest indicator that it could have, because it is very similar to pedestrian to pedestrian communication. A robot that chooses a side far ahead, eliminates all the doubts and discomfort of it driving straight towards you.

What is the influence of intent indicators on the crossing interaction between pedestrian and delivery robot?

The setup of the test, in which the robots had a fixed behavior and the participants had to react to this, will influence how the crossing interaction takes place. The participants had a reactive role and were not able to take initiative (in the scenarios without gesture communication). In real-life this is not the desired interaction, since the pedestrian has a subordinate role and needs to do adapt to the robot. The participants in the test were not sure if the robot was also able to react on their presence, which put them even more in a reactive situation. The final design of the robot should allow more initiative for the pedestrians. Pedestrians should be able to make a decision about their path, while having the confidence that the robot will adapt.

Because the participants had to react to the robot and the robot didn't communicate much intents by taking a clear path, a lot of the participants focus had to be on the robots intent indicators. The test showed that not all participants were natural focusing on this and were therefore missing cues. It could also be argumented that if pedestrians are operating in a complex situation, with lots of other pedestrians and obstacles, they have less attention on the robots indicators, which are positioned quite low in their field of view.

Using the intent indicators as the main cue from the robot, will be hard to establish. The test showed that the timing of the indicator is important and that it was often experienced as late. Participants often needed to wait on the indication before they could comfortably make a decision on which side of the obstacle to go to. Using a clear path by the robot and an easily readable "body language" will be more comfortable for pedestrians, since it is the same as what they look for in other pedestrians. Intent indicators could have a supportive role, if the robot needs to make a very sharp turn, needs to go around the corner, in dangerous situations or when the robot will maneuver itself to a position on the sidewalk where it will wait for a customer. For small movements, no intent indicators will be used, which prevents it from indicating all the time, while it is maneuvering in crowded environments. This more selective utilization of the indicators increases the perceived importance.

How well are the two designed intent indicators perceived and understood?
The blinker of the led bar is perceived as a strong indicator that is both good visible and understandable. The continuous blinking grabs the attention and is perceived at every instance the pedestrian looks at it. The association with cars is very strong, making it highly understandable to read the intent of the robot. The blinking was not the standard blink, but a more sideways movement, like in expensive cars. This didn't seem to affect the understandability negatively.

The braking animation of the led bar was sufficiently visible. However, on first encounter, it is not understood as an indicator for deceleration. Associations with turning off of products or batteries dying, was mentioned. It seems to be an indication which will be linked to the deceleration in just one or two encounters. The only association with other products that are braking is the rear braking light of a car. This could be used on the back of the robot, however, this will be confusing on the front. A red light or red led bar might also be seen as too aggressive and bring up associations with movies like I, Robot, in which mutant robots have red lights in their chest plates.

The indication of the eyes which look in the intended direction, turns out to be poorly visible in the test. Besides being too subtle and harder visible in VR, it also is not a natural way that pedestrians interact with other pedestrians. Eyes look into all directions, like points of interest and to other people. Pedestrians will not immediately link the eyes of the robot to its intentions. Dynamic eyes could better be used to simulate awareness of the environment. Pedestrians might find it more comfortable if they see a robot which is actively "looking" at its environment and to them.

How do posture gestures influence the crossing interaction between pedestrian and delivery robot?
When being able to communicate with gestures, participants took more initiative in choosing a side to go to, while hesitating less. In that way, this extra sense of control had a positive effect. However, the gestures created confusion. Three participants made an arm gesture in the direction that they were going to (only looking at the first time they perform a gesture). Four times participants pointed the robot to go somewhere. One tried to stop the robot. And there were two participants who didn't perform a gesture. There is no consensus on how to interact with robots by gestures, which will make implementation complicated. It will lead to confusions, especially when there are more companies implementing sidewalk robots. This confusion can work negatively for the perceived comfort, when the pedestrian expects the robot to listen to a gesture, but it doesn't do so. Especially in complex and busy situations, a robot might not be able to react on all gestures, since it also needs to take into account other entities in the environment and potential other gestures.

What posture gestures do pedestrians think will yield good pedestrian-robot interactions that will help them to cross each other comfortably?
In general, the gestures that the participants performed were with a clear raise of the hand, higher than the elbow. All gestures were more subtle than how cyclists raise their arm. The performed gestures are likely to be recognizable with computer vision, but there could be false positives if pedestrians wave to each other or take out their phone from their pocket.

The participants that didn't perform a gesture and saw their total posture and position on the sidewalk as their cue to the robot, indicated that this felt natural (average of 5,4). This is slightly better than pointing the robot where it needs to go (average of 5,0) and highly better than pointing in your own direction (average of 3,5).

Since performing no gesture feels the most natural, it requires no extra effort from pedestrians and creates the least confusion, this is the best solution. During the development of the robot, there could better be more investment in optimizing how well the robot perceives pedestrian behavior, than to implement gesture communication in society.

Conclusion summary
Some strong insights were gained by the VR user experience test. Implementing an intent indicator on the robot has a positive effect on the perceived comfort by the pedestrian, for scenarios in which it is not possible to see what the robot is going to do in another way. This is only true if the indicator is both highly visible and understandable. The turning and braking indicator on the robot with the led bar is both better visible and more understandable than a robot with eyes which look into the driving direction. The led bar's orange blinking light has a strong association with car directional lights and is therefore recognized without doubt by the pedestrians. The led bar also has a positive effect on the "kindness" of the robot, because the "mouth" makes the robot more human.

Intent indicators should not be utilized for every movement the robot makes. If the robot is acting in a busy situation, it should first of all be solved by taking a path which solves the situation best and should be set in early, so pedestrians can adapt their path early on. This is very similar to pedestrians interact with other pedestrians and therefore uses the same mental models.

Using gestures to communicate with the robot about who is going to which direction is not seen as a natural interaction. Pedestrians don't do this in real-life and using interactions from for instance cycling are not easily implemented in the sidewalk context. Gestures become very confusing, because different people use similar gestures to communicate different things. If the robot then reacts unexpectedly, it can both become dangerous and irritating for the pedestrian.

Robot behavior simulation
Appendix F

Goals of the simulation
The user experience VR test gave some good insights about reactions of pedestrians to delivery robot. However, the situation was highly simplified and doesn't take into account the complex scenario of multiple pedestrians on a sidewalk. Building simulations is at this point the only method, within the available resources, to gain insights about good robot behavior in complex environments. The goals of this explorative research are:

- Design a robot logic that is based on the movement of pedestrians, so it feels familiar and predictable.
- Determine how much initiative the robot should take or how reserved it should be.
- Point out situations in which the robot should and shouldn't use an intent indicator.
- Design robot logic that transcends the human logic and helps to solve situations better.

Model setup
Unreal Engine 4 makes use of blueprints, which is a node-based way of coding interactive environments. In figure F1, the simulation environment can be seen. Different pedestrian pawns are located on a 3 meter wide sidewalk. The two groups of pedestrians walk towards each other, towards a target point in the distance. On either side of the sidewalk, there is an obstacle actor, which is invisible during simulating, but can be sensed by the pedestrians. The pedestrian pawns maneuver based on their blueprint, in which they sense the entities in their environment, which act out a force on them. The total sum of the attractive forces from the target point and the repelling forces from other pedestrians and obstacles, determines the robot's walking direction and velocity. Every 0,05 seconds, their movement is updated. Pedestrians can pivot around their axis and are therefore quite agile. The robot also acts based on the social forces model, but has different parameters and a less agile vehicle movement.

Pedestrian Pawn Blueprint
In figure F2, a simplified overview can be seen of the Pedestrian Pawn blueprint. In figure F5, the section in which other pedestrians are sensed, can be seen. The main principle of the blueprint is that a pedestrian senses all entities in a radius of 5 meter and calculates their force. The distance and angle towards the entity is put into a curve, which outputs the importance of this entity. For instance, pedestrians straight in front and at close range, have a higher importance than entities on the side and far away. The vector opposite to the sensed entity is normalized and multiplied with the factors of importance. The outcome of this is a vector, which is offset by 15 degrees for the pedestrian and robot force, since they are dynamic. This makes sure

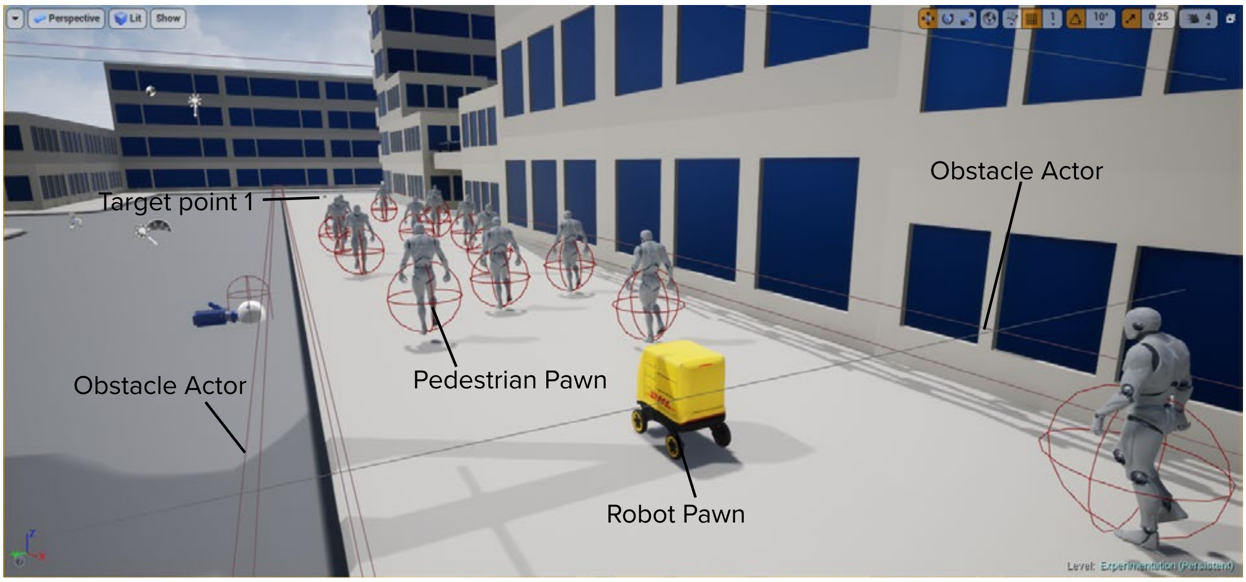


Figure F1. Simulation environment with the different actors.

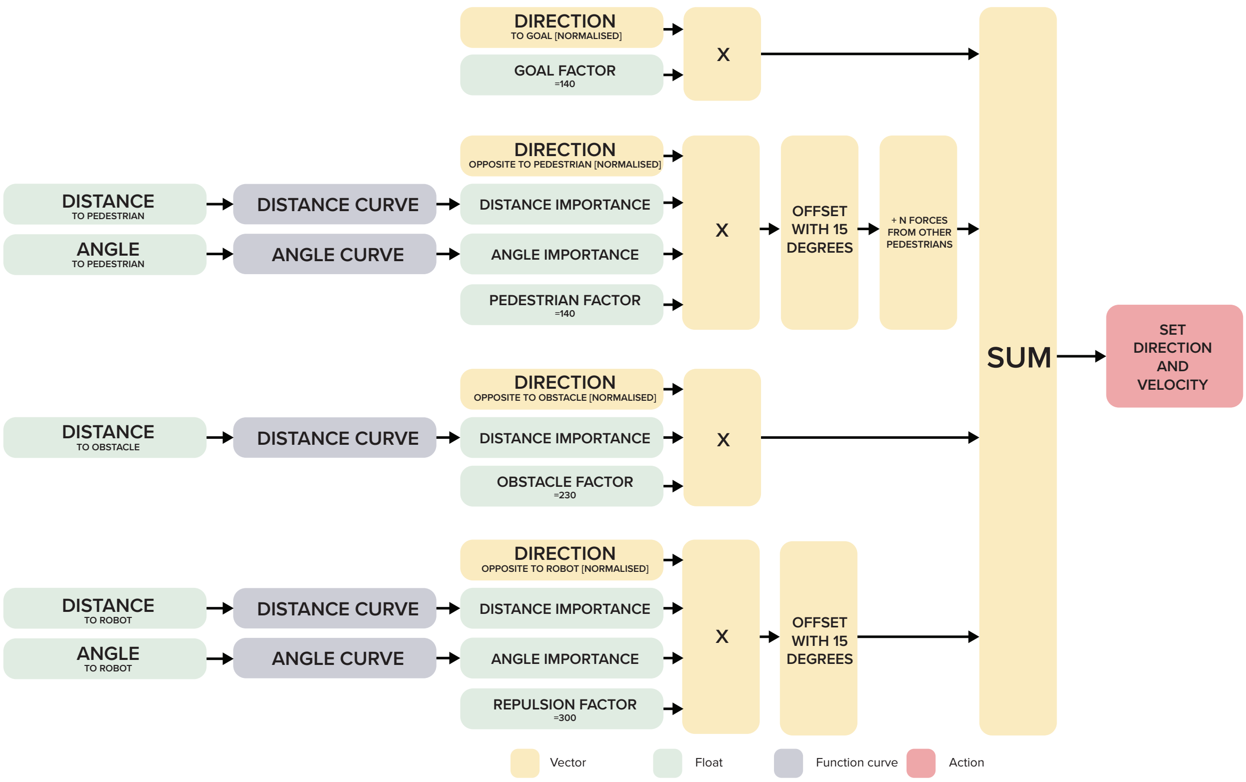


Figure F2. Simplified representation of the pedestrian pawn blueprint.

that there is more sideways component and that entities move easier to the side, than that they accelerate. There can be more than one pedestrian in the sensed environment, so all these forces are add up to create a total pedestrian force. The sum of attraction and repulsion forces determines the final direction and velocity of the pedestrian. See figure F4 for an overview of the Pedestrian Pawn Blueprint and figure F5 for the specific section that calculates the repelling forces from pedestrians.

Robot Pawn Blueprint

The blueprint of the robot is similar, in that it operates based on the social forces model. However, the sum of the forces doesn't directly update the rotation of the robot, but updates the steering of the wheels, as well as the throttle. In this way, the robot will always have a realistic movement, which is based on physics. This means that it takes time to accelerate, brake and that the robot has a wider turning angle.

See figure F3 for a simplified representation for the robot pawn blueprint. The robot is not programmed to react to other robots in the environment. Another difference can be seen with the rotation offset on the repulsion forces from the pedestrians, which can either increase or decrease the sideways component of the robot. This last change will be explained in the results section of this chapter.

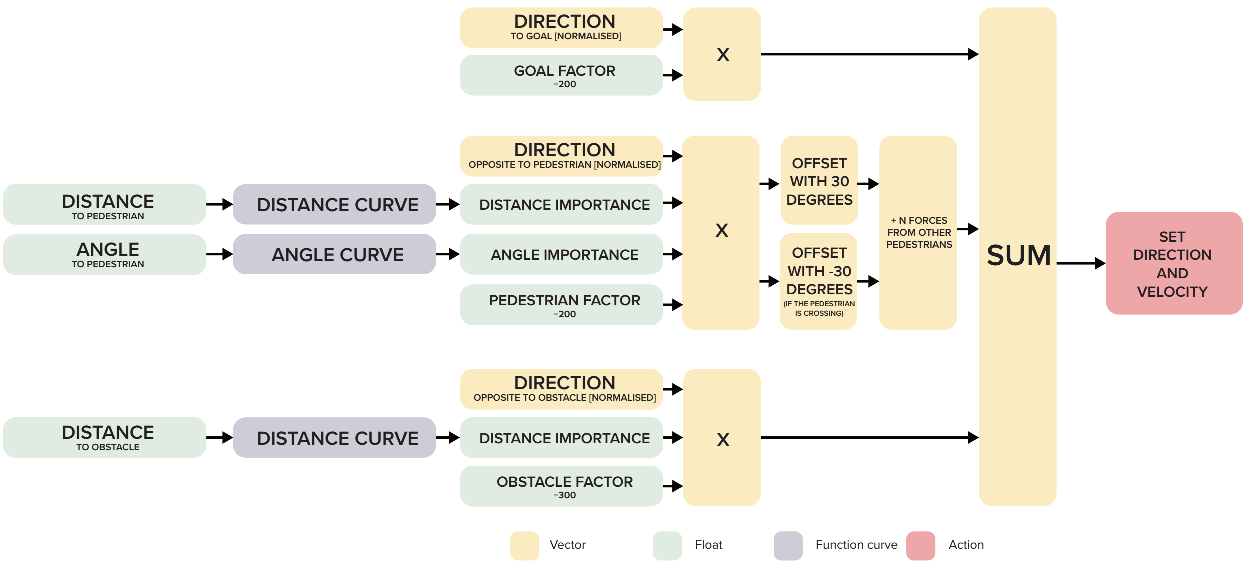


Figure F3. Simplified representation of the robot pawn blueprint.

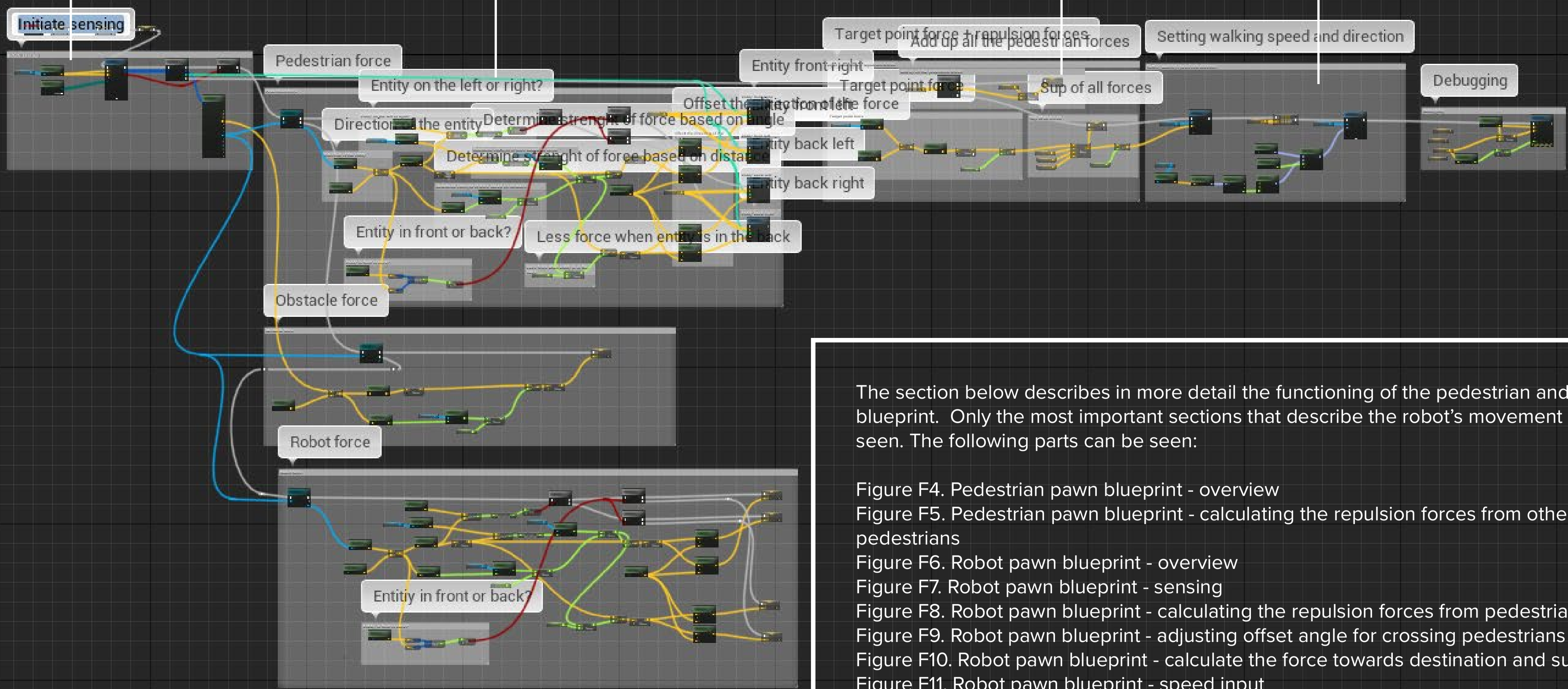
PEDESTRIAN PAWN BLUEPRINT
OVERVIEW

Initiating sensing by using a sphere trace to find all entities within a radius of 5,5m.

Per entity the repulsion force is calculated based on the distance and angle. The top block is for the pedestrians, if the entity is not a pedestrian, it is checked in the middle block if it is an obstacle, if not, the lower block checks if it is the robot.

The attraction force of the final destination is calculated based on the direction and the desired speed of walking. Furthermore, the sum of the attraction force and repulsion forces is calculated.

The linear velocity of the pedestrian is set based on the sum of the forces. The pedestrian is also rotated into the walking direction.



The section below describes in more detail the functioning of the pedestrian and robot blueprint. Only the most important sections that describe the robot's movement can be seen. The following parts can be seen:

Figure F4. Pedestrian pawn blueprint - overview
Figure F5. Pedestrian pawn blueprint - calculating the repulsion forces from other pedestrians
Figure F6. Robot pawn blueprint - overview
Figure F7. Robot pawn blueprint - sensing
Figure F8. Robot pawn blueprint - calculating the repulsion forces from pedestrians
Figure F9. Robot pawn blueprint - adjusting offset angle for crossing pedestrians
Figure F10. Robot pawn blueprint - calculate the force towards destination and sum of forces
Figure F11. Robot pawn blueprint - speed input

Figure F4. Pedestrian Pawn Blueprint - Overview.

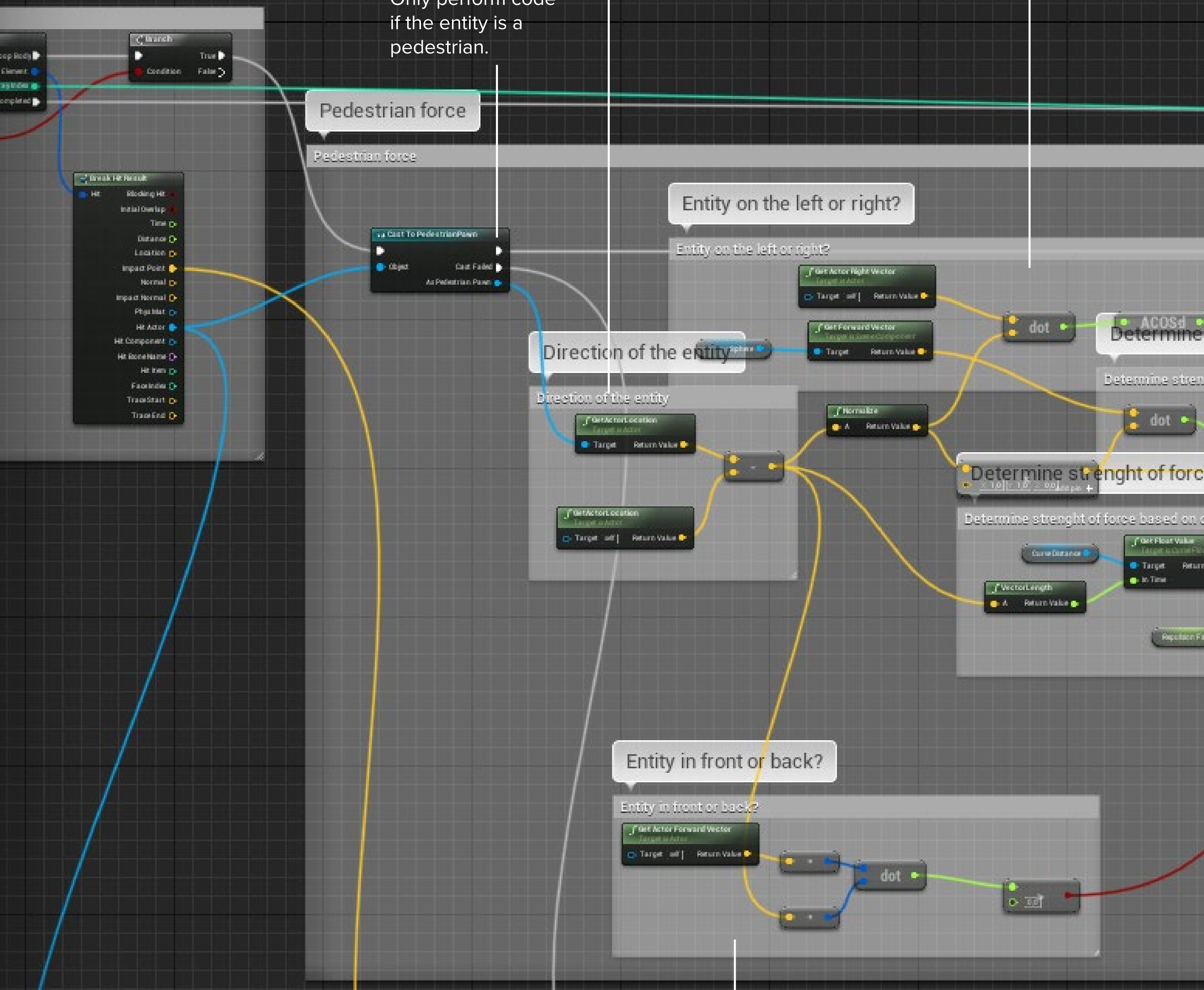
PEDESTRIAN PAWN BLUEPRINT
REPULSION FORCES PEDESTRIANS

It is first checked if the entity is a pedestrian.

Retract the entity position from the personal position to find the vector towards the entity.

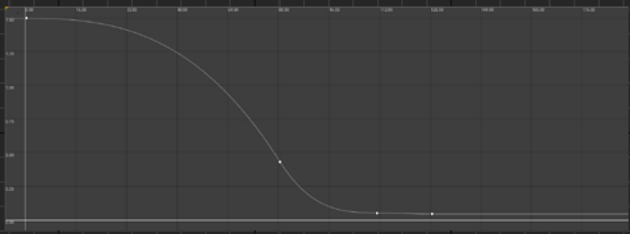
Calculate if the entity is on the left or right. The angle between the vector towards the entity and the personal right vector is calculated with the dot product. If the angle is smaller than 90 degrees, the entity is on the right.

Only perform code if the entity is a pedestrian.



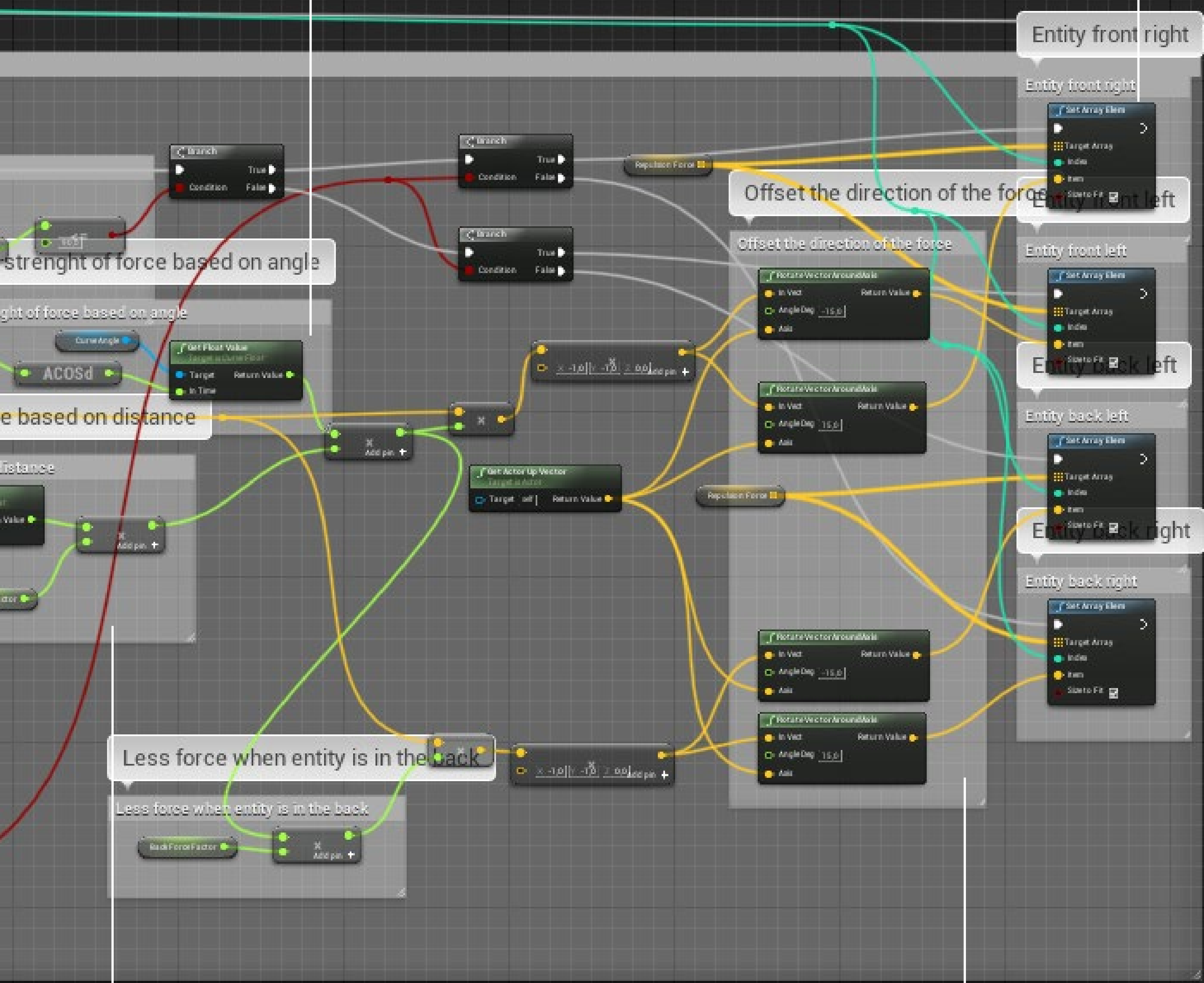
Calculate if the entity is in the front or back. The dot product of the vector towards the entity and the personal forward vector is positive when the entity is in front. Entities on the back only have 0,4 times the calculated force, since the entity is out of sight.

Figure F5. Pedestrian Pawn Blueprint - Calculate the repulsion force experienced by other pedestrians.



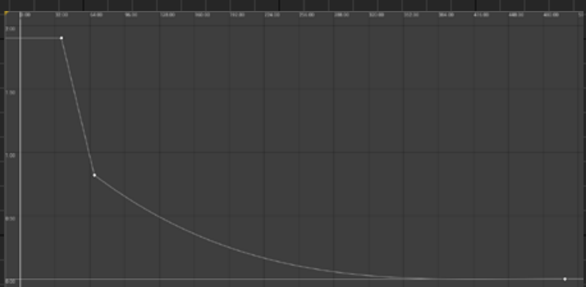
The output is put into an array, because if there are more pedestrians sensed, the calculation will be done multiple times.

The angle towards the entity is inputted into a curve. Entities straight in front have more effect than on the side. The output is a value from 0 till 1,5.



The distance towards the entity is found with the vector length. This is inputed into a curve, which has resemblance with a quadratic curve. The output is a value between 0 and 1,9. This value is multiplied by the repulsion force, which is a constant value of 140, found by experimentation with different goal and repulsion ratio's.

The force, based on the repulsion factor, the angle and the distance is rotated by 15 degrees. This creates more sideways component, which makes the pedestrian go more to the side, than decelerate when approaching someone from the front.

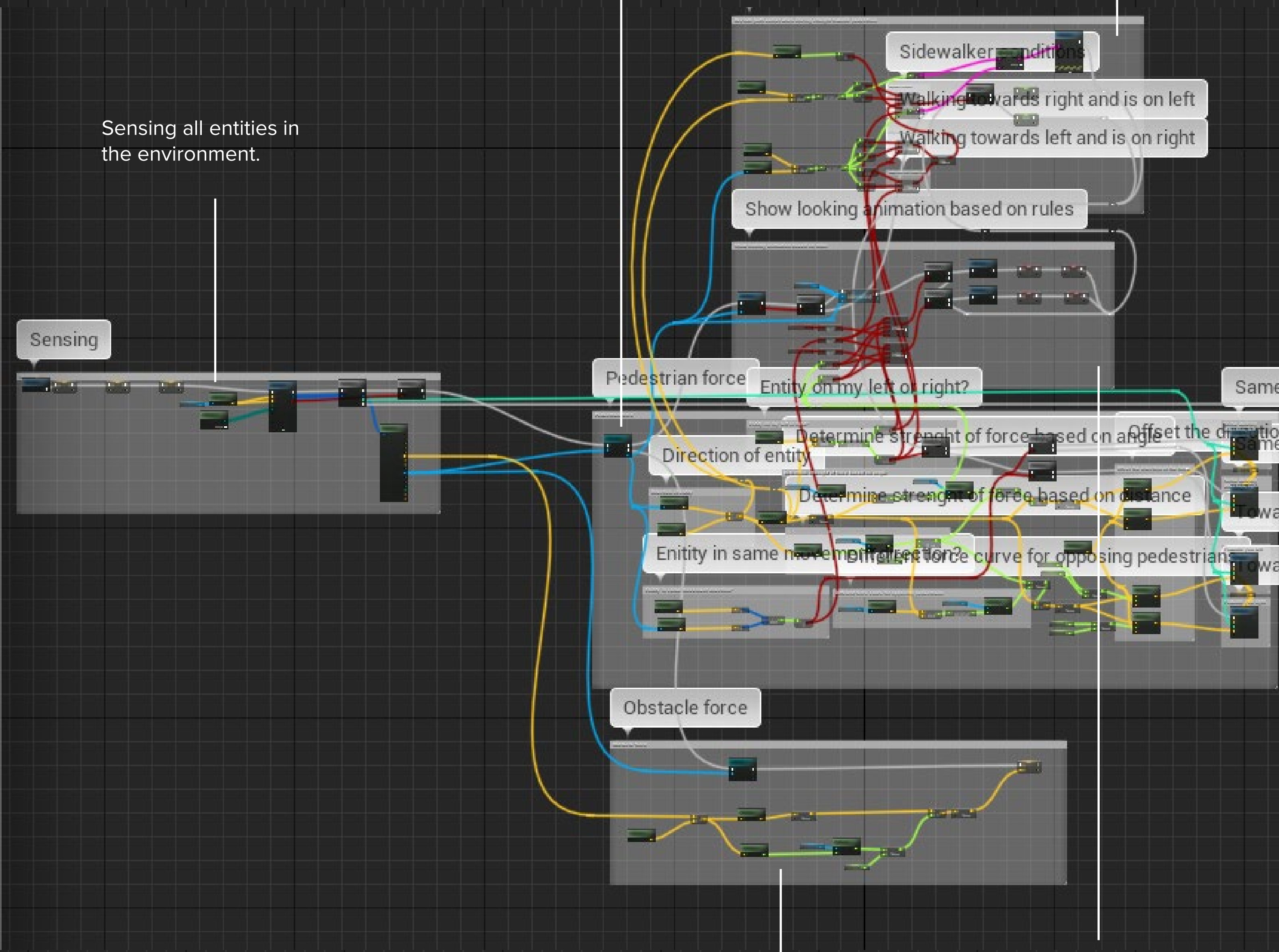


ROBOT PAWN BLUEPRINT
OVERVIEW

It is calculated if pedestrians that walk straight up to the robot are going to cross the robot or keeping the same side. This manipulates the result of the repulsion forces calculation.

Calculation of the repulsion forces from all sensed pedestrians.

Sensing all entities in the environment.



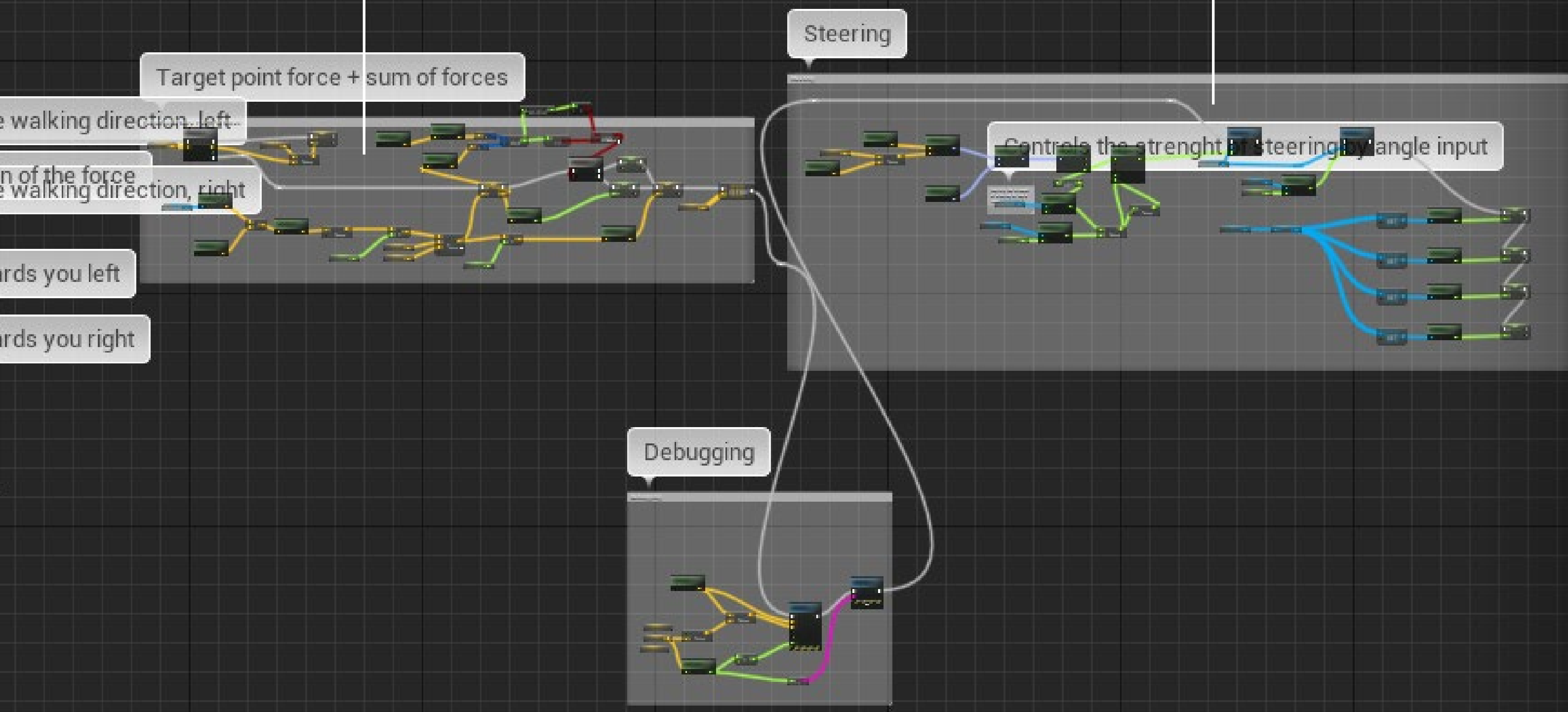
The animation of the eyes is established here. There are a few conditions that regulate if the robot will look at a pedestrian.

Calculate the forces coming from the borders and obstacles.

Figure F6. Robot Pawn Blueprint - Overview

The attraction force of the final destination is calculated and a sum of all forces is made.

The robot needs more manipulations to translate the total force into wheel and throttle movement. This is done here.



ROBOT PAWN BLUEPRINT
SENSING ENTITIES

Resetting all forces to zero, so the calculation is only done with new information.

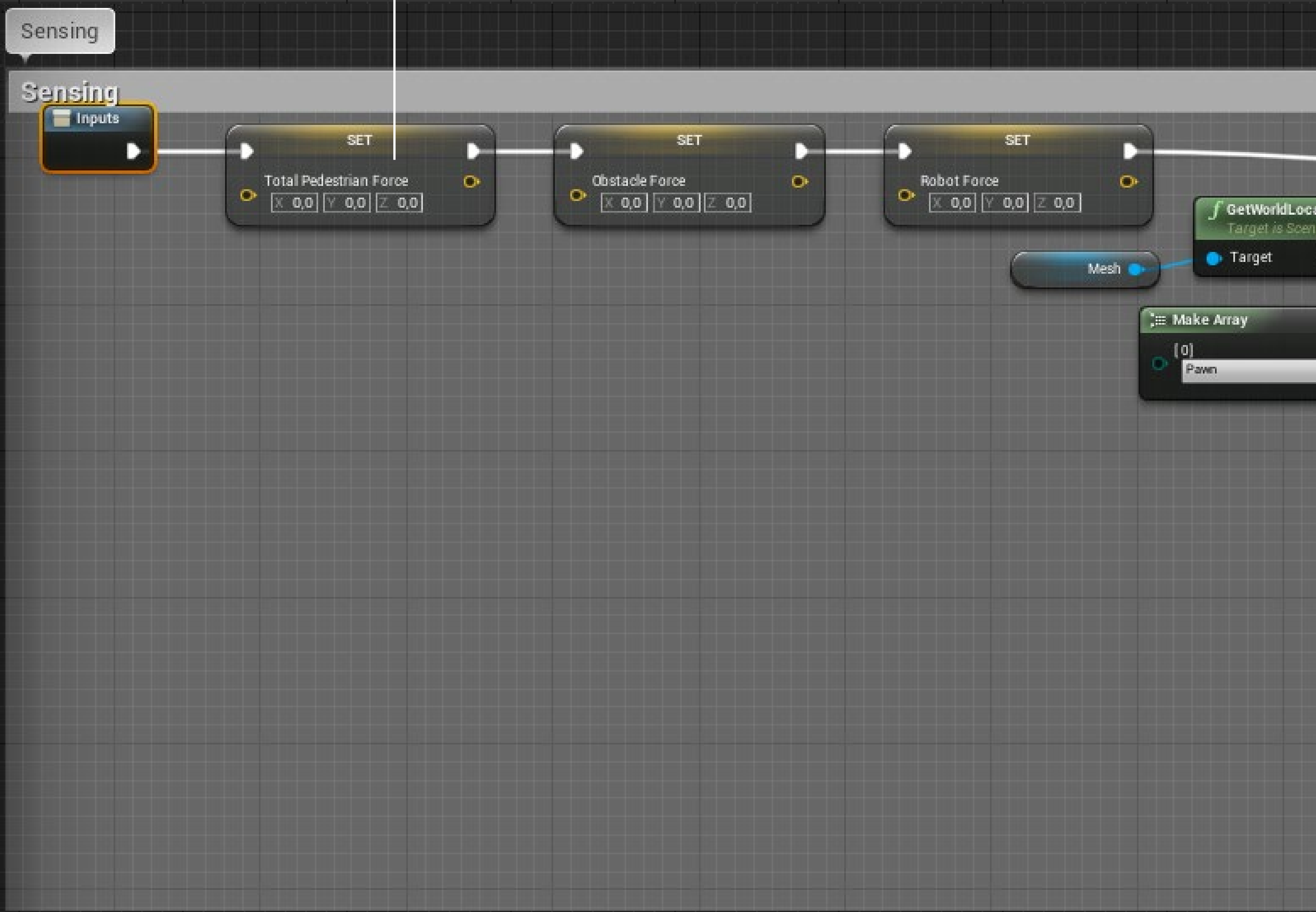
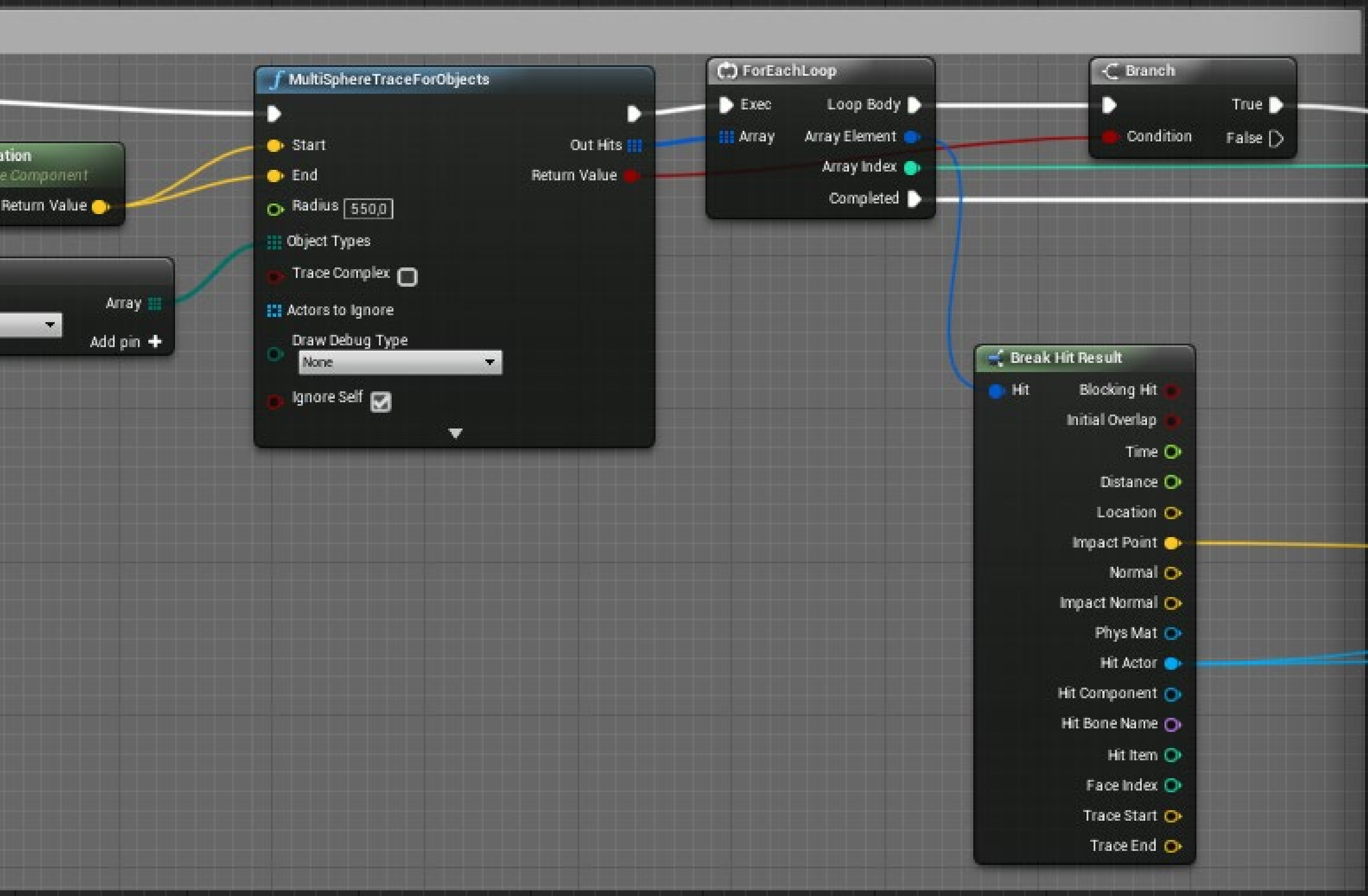


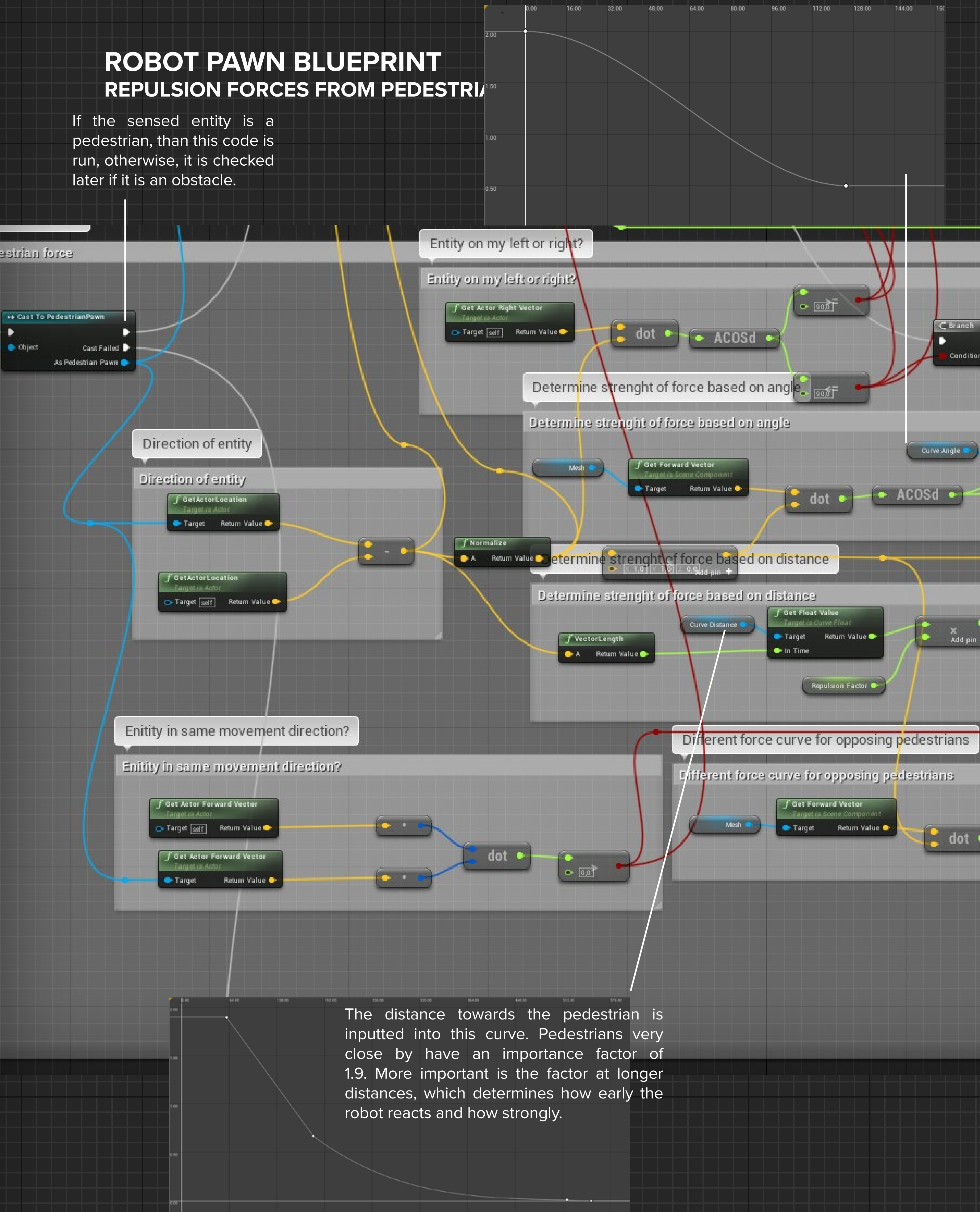
Figure F7. Robot Pawn Blueprint - Sensing all entities in a specified radius.



MultiSphereTraceForObjects
Start
End
Radius 550,0
Object Types
Trace Complex
Actors to Ignore
Draw Debug Type
None
Ignore Self
Out Hits
Return Value
Return Value
Array
Add pin
ForEachLoop
Exec
Array
Loop Body
Array Element
Array Index
Completed
Branch
Condition
True
False
Break Hit Result
Hit
Blocking Hit
Initial Overlap
Time
Distance
Location
Impact Point
Normal
Impact Normal
Phys Mat
Hit Actor
Hit Component
Hit Bone Name
Hit Item
Face Index
Trace Start
Trace End

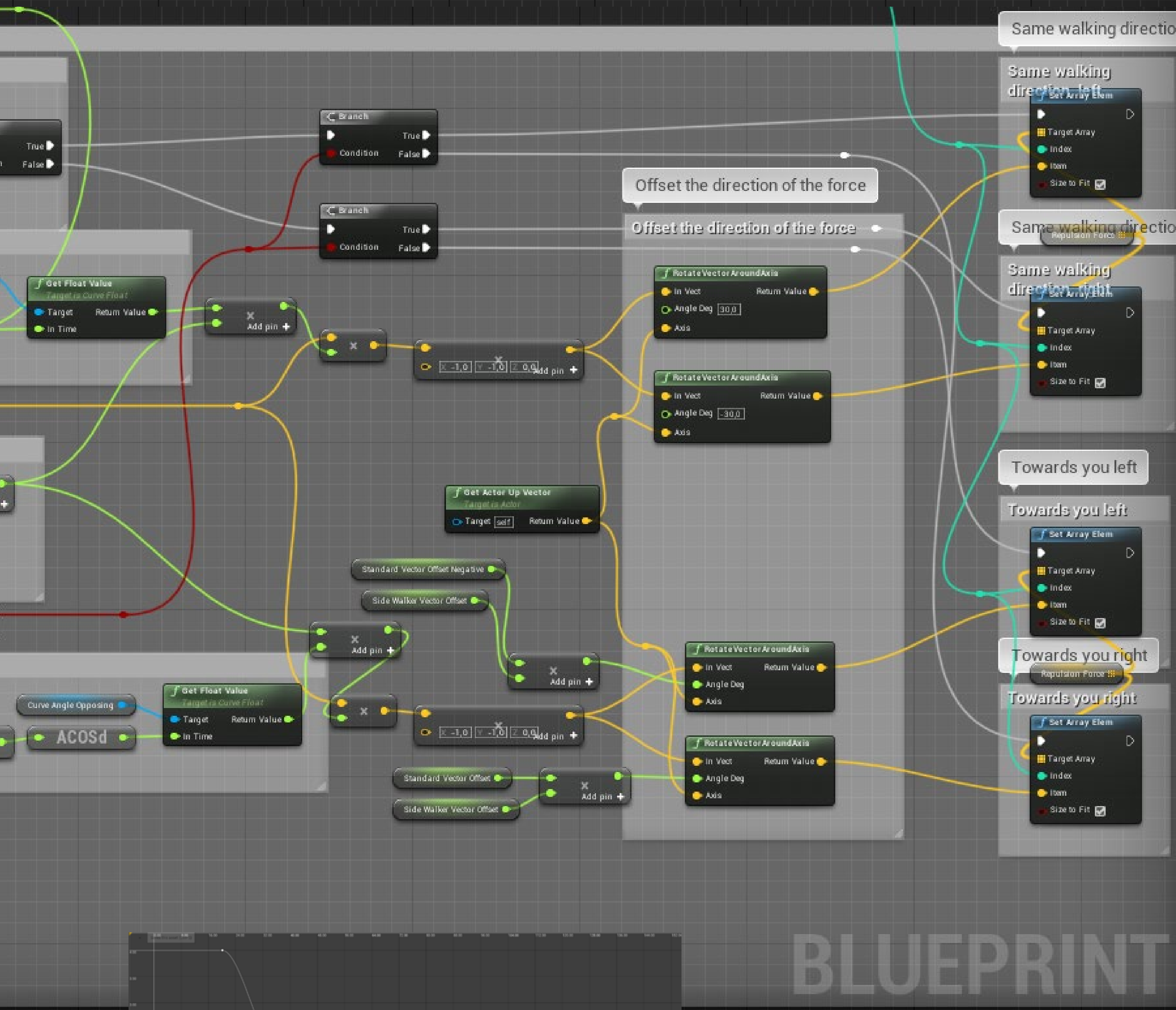
ROBOT PAWN BLUEPRINT
REPULSION FORCES FROM PEDESTRIANS

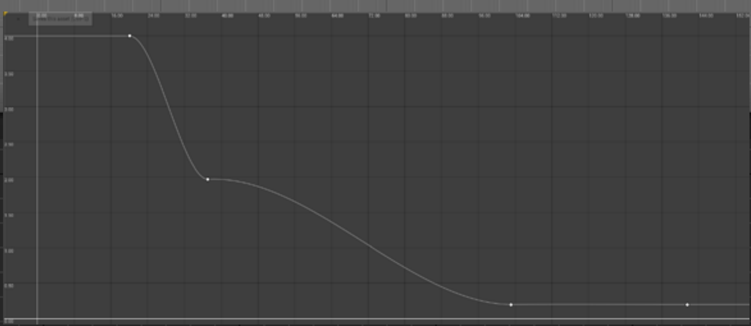
If the sensed entity is a pedestrian, than this code is run, otherwise, it is checked later if it is an obstacle.



The distance towards the pedestrian is inputted into this curve. Pedestrians very close by have an importance factor of 1.9. More important is the factor at longer distances, which determines how early the robot reacts and how strongly.

Figure F8. Robot Pawn Blueprint - Calculating repulsion forces from pedestrians.



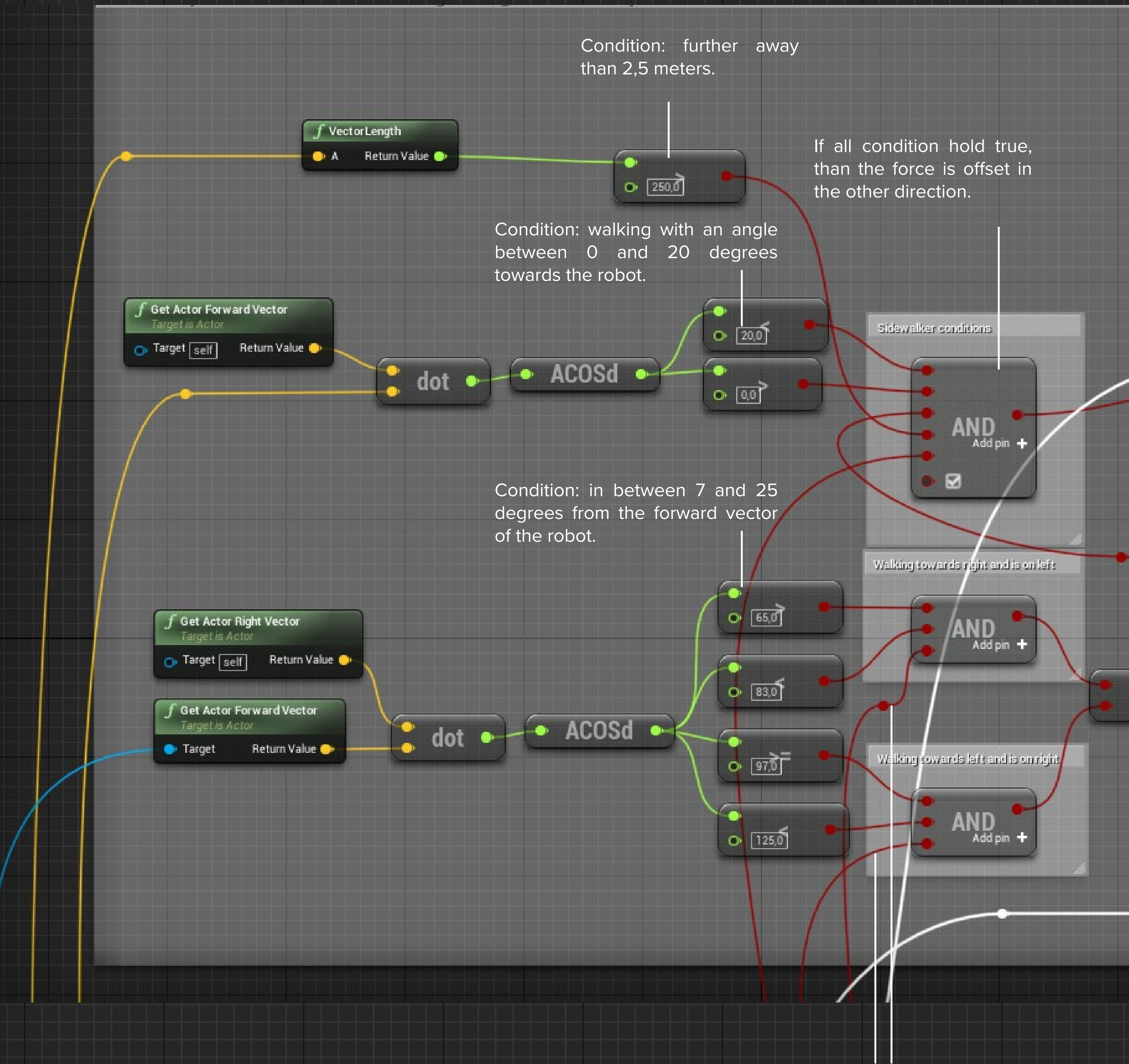


Pedestrians walking into the opposite direction have a different importance of their angle. Straight in front has an importance factor of 4, since there is a higher chance of collision, and the robot needs some space for steering.

ROBOT PAWN BLUEPRINT

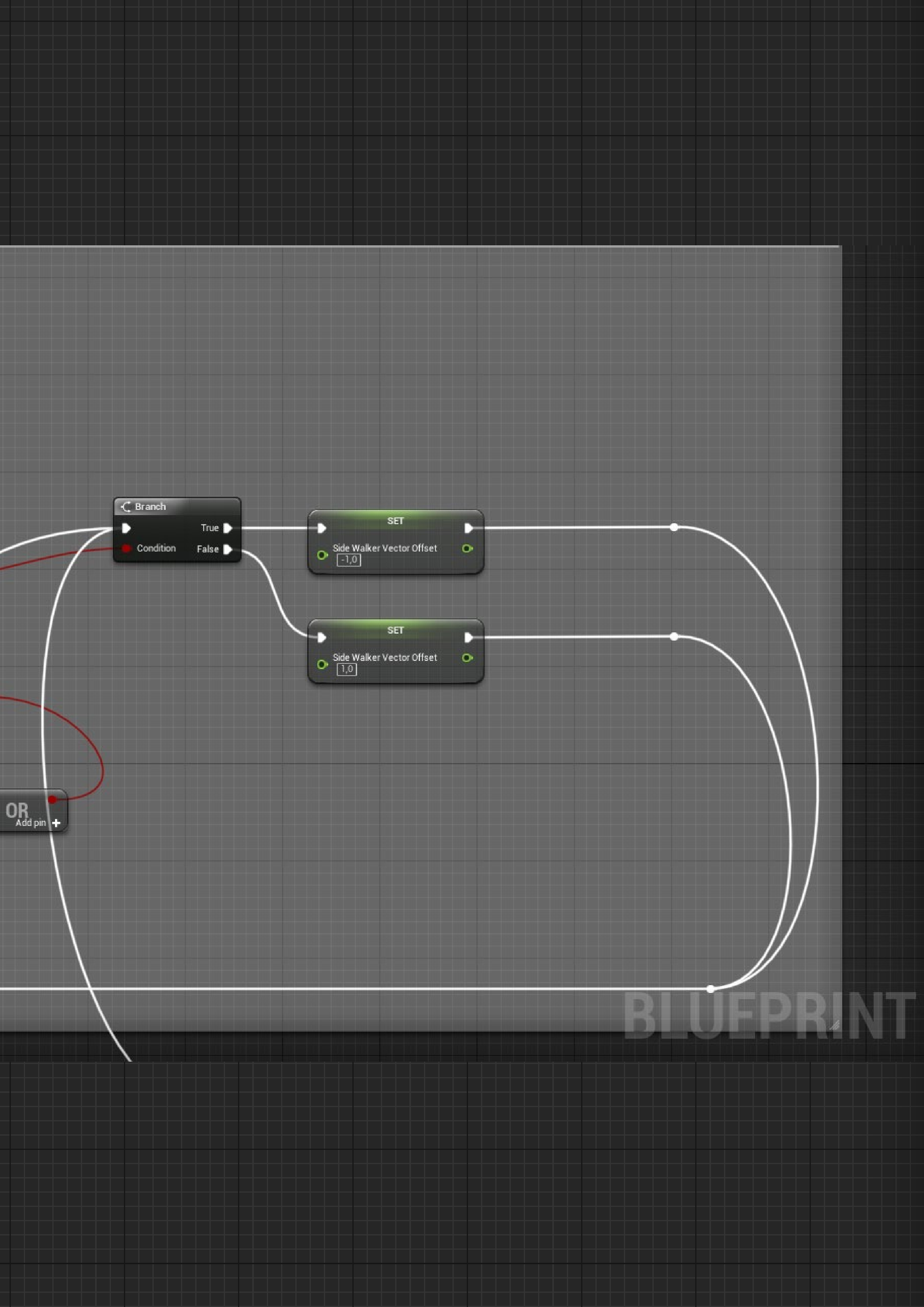
CROSSING PEDESTRIANS

If pedestrians are walking straight up to the robot, but are crossing to the other side, the robot should not be fooled to walk in the same direction. E.g. a pedestrian could be on the right side of the robot, but walking towards the left side. Normally the robot would move to the left, based on the current position of the pedestrian. In this part of the blueprint it is sensed if the robot should adjust its movement to the right, to go behind the crossing pedestrian.



Condition: position on one side, but walking to the other side.

Figure F9. Robot Pawn Blueprint - Determining if the robot should behave differently when pedestrians are crossing the robot.


Branch
True
Condition
False
SET
Side Walker Vector Offset
-1,0
SET
Side Walker Vector Offset
1,0
OR
Add pin
BLUEPRINT

ROBOT PAWN BLUEPRINT
SUM FORCE

All the forces from the different pedestrians are summed up to get a total pedestrian force.

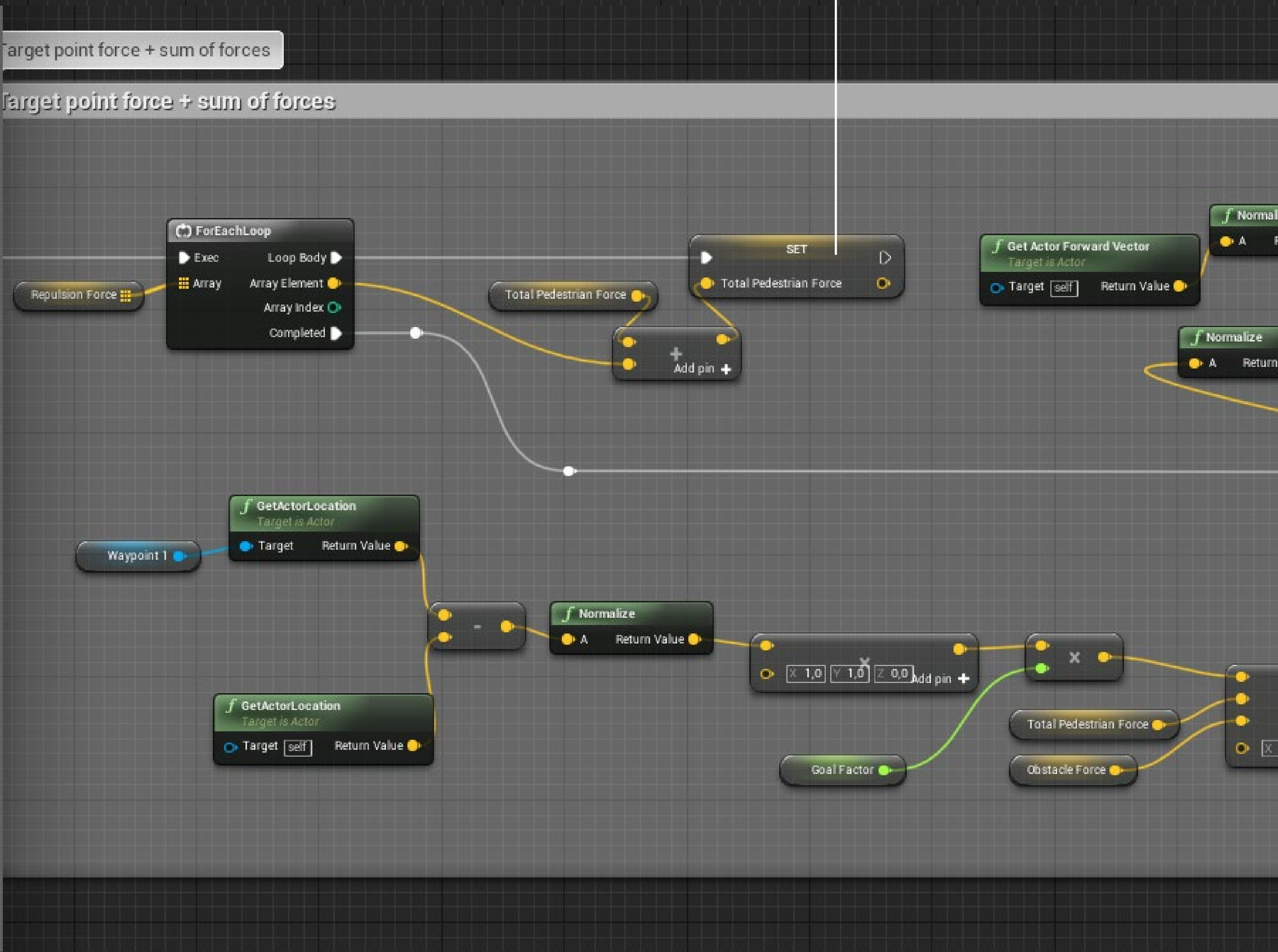
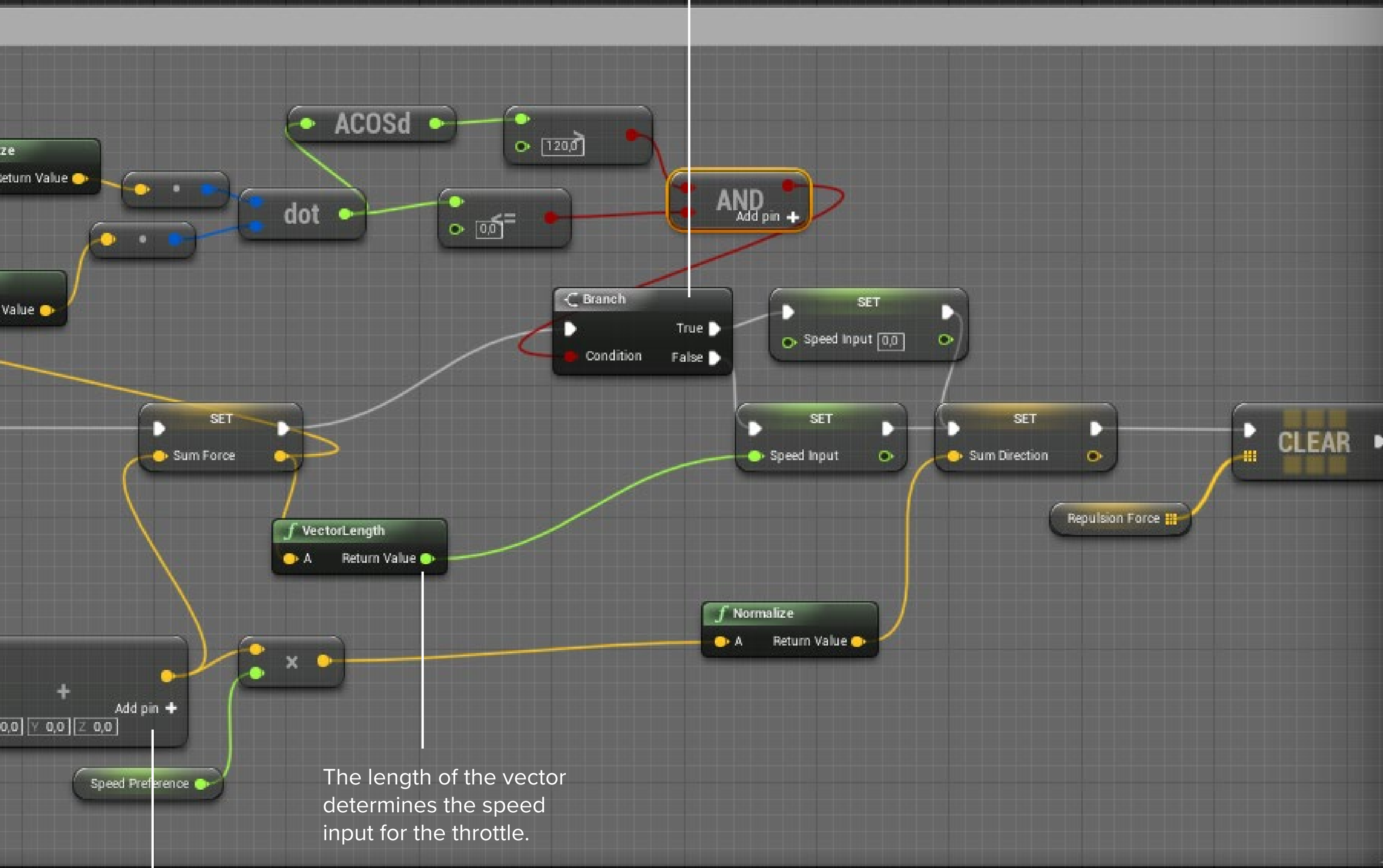


Figure F10. Robot Pawn Blueprint - Calculating the overall force.

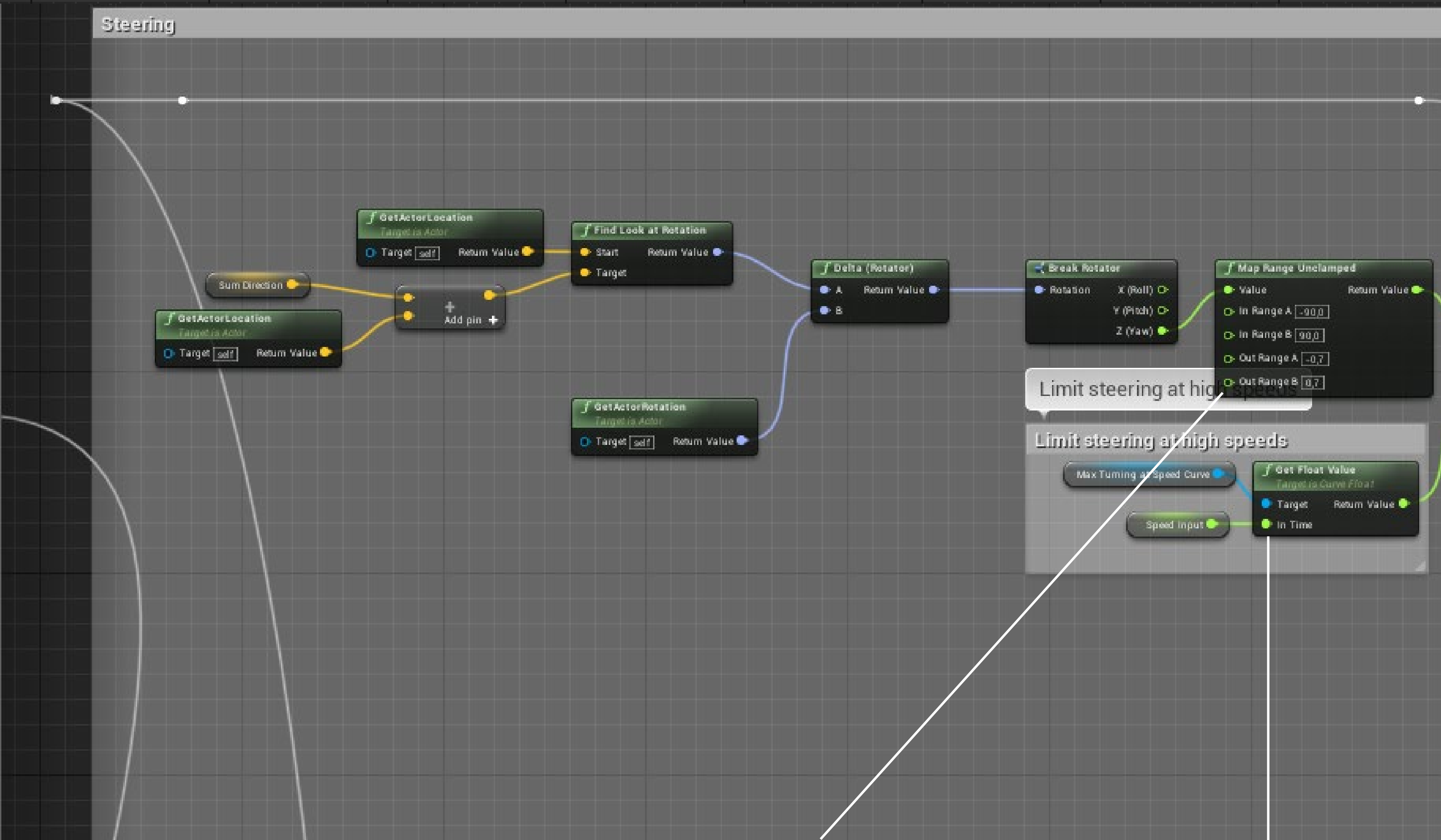
In this simulation, the robot can only move forward. So the speed input will be set to 0 if the sum force is in the opposite direction and more than 120 degrees.



The length of the vector determines the speed input for the throttle.

The sum is made of the total pedestrian force, obstacle force and goal force.

ROBOT PAWN BLUEPRINT
ROBOT MOVEMENT



The degrees toward the direction of the force is translated into a steering input.

At high speeds the robot needs less steering, to deviate its path. Therefore the steering input is multiplied by a value coming out of this curve.

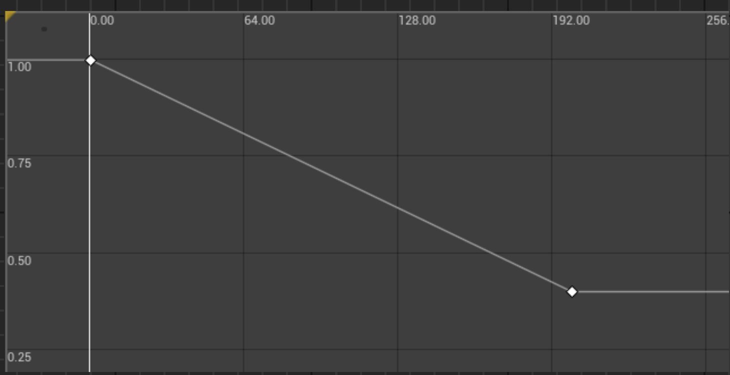
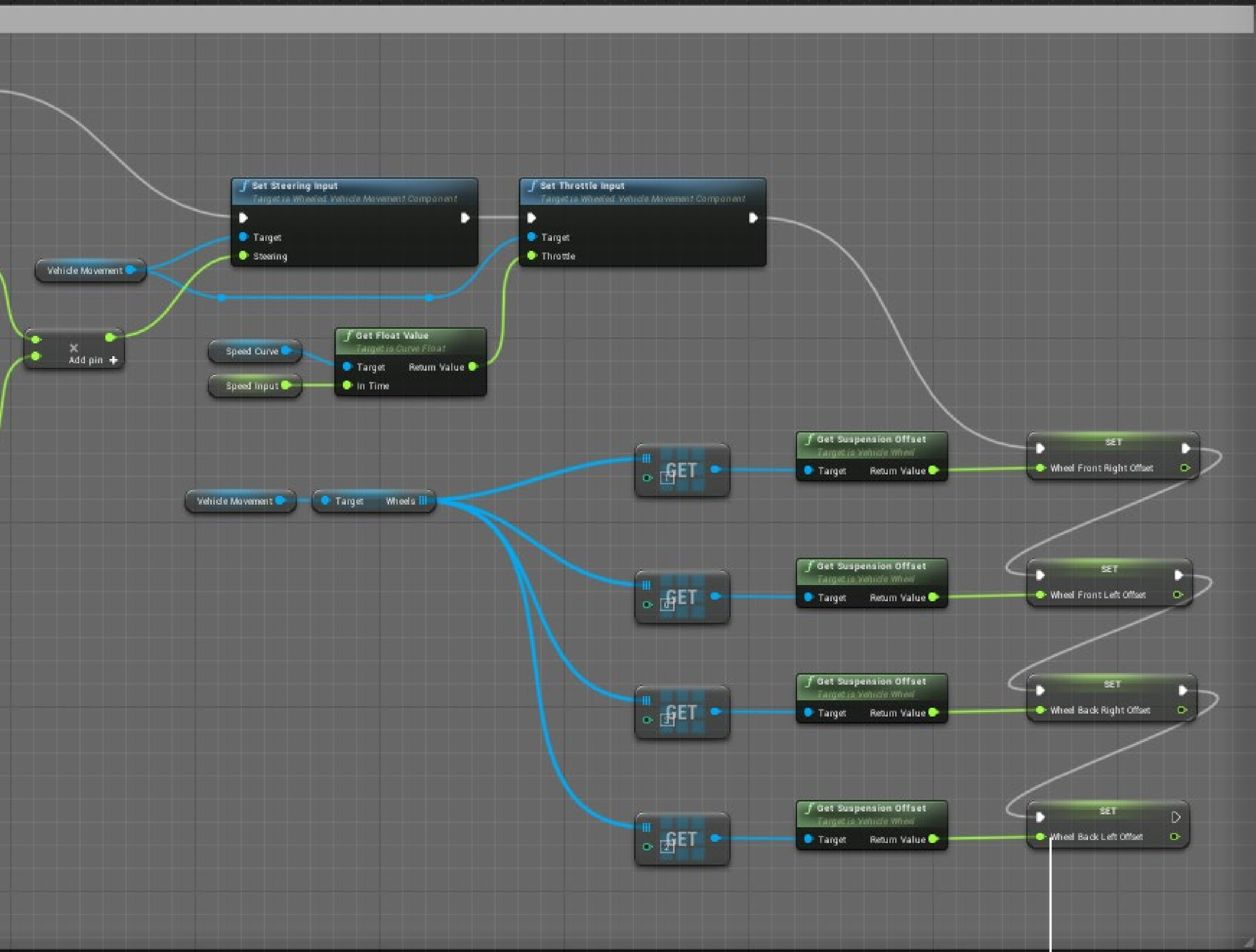


Figure F11. Robot Pawn Blueprint - Inputting the total force into the robot's steering and throttle.



The wheels move dynamically based on the suspension of the vehicle. The legs of the robot are set to match the wheel movement.

Results

The results of the simulation consists of the choices made in the model, the forthcoming robot behavior and the insights gained along the way. The opinions of potential users will be discussed in appendix G.

Angular offset of repulsion forces

In the original social forces literature, the repulsion forces from pedestrians were directed in the direct opposite direction of that pedestrian. However, this results in a sum force which is not affecting the sideways movement much and results mostly in deceleration. By offsetting the repulsion force with 30 degrees, the robot is more inclined to steer to the side and there is less speed reduction.

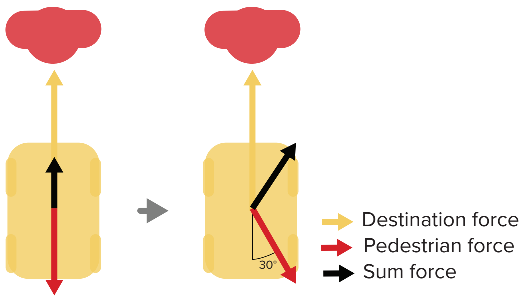


Figure F12. Angular offset of repulsion forces.

Distance importance curve

The distance towards a pedestrian is inputted in the curve in figure F13. The outcome is an importance factor, influencing how large the force from this pedestrian will be taken into account when calculating the sum force. The plateau up till 60 centimeters and with importance of 1.9, is the area which, for safety reasons pedestrians may not enter. The other way around, it also represents the personal area of pedestrians, which the robot may not enter. In social forces literature, the distance curve is described as an exponential function. This part is represented in the rest of the curve. The control point is dragged to the right more, so at middle-long distances, the robot reacts more strongly to pedestrians. At 5,5 meters, the curve smoothly starts, so the repulsion force gradually builds up and the robot reacts smoothly. Increasing the importance at large distance is a tempting method to make the robot react very early to pedestrians. This works well when encountering one pedestrian. The robot will deviate its path quite early. However, on crowded sidewalks, this results in the robot experiencing significantly high forces, from all entities within the sensed range. The sum of the forces, is too large, which makes the robot stop and stand still till all pedestrians have passed. This already happened with slight increases of the control point at 5 meters.

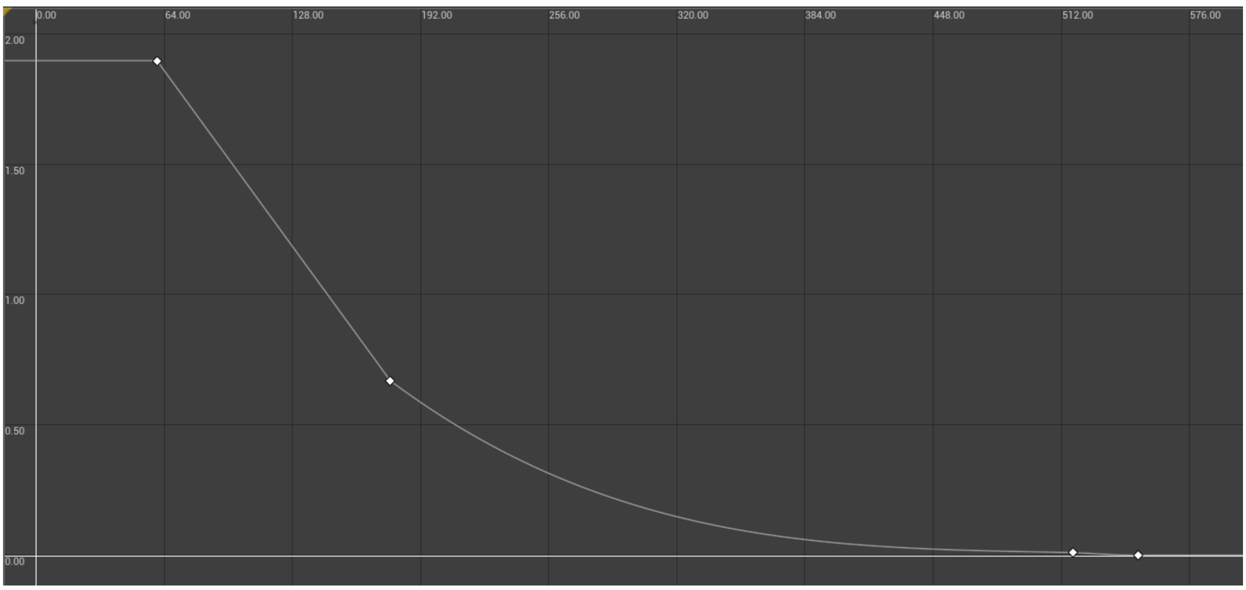


Figure F13. Importance curve for the distance of the sensed pedestrian. (x=distance, y=importance factor)

Directional importance curve for opposing pedestrians

The angle towards the sensed pedestrian is inputted into the curve in figure F14, which outputs an importance factor for that pedestrian. This specific curve is used for pedestrians that are walking in the opposite direction than the robot. The area straight in front of the robot has the highest importance, since the chance of a confrontation or collisions is the highest. The needed steering radius of the robot has the result that the robot needs more space in front, to get out of the way of a pedestrian. The importance factor

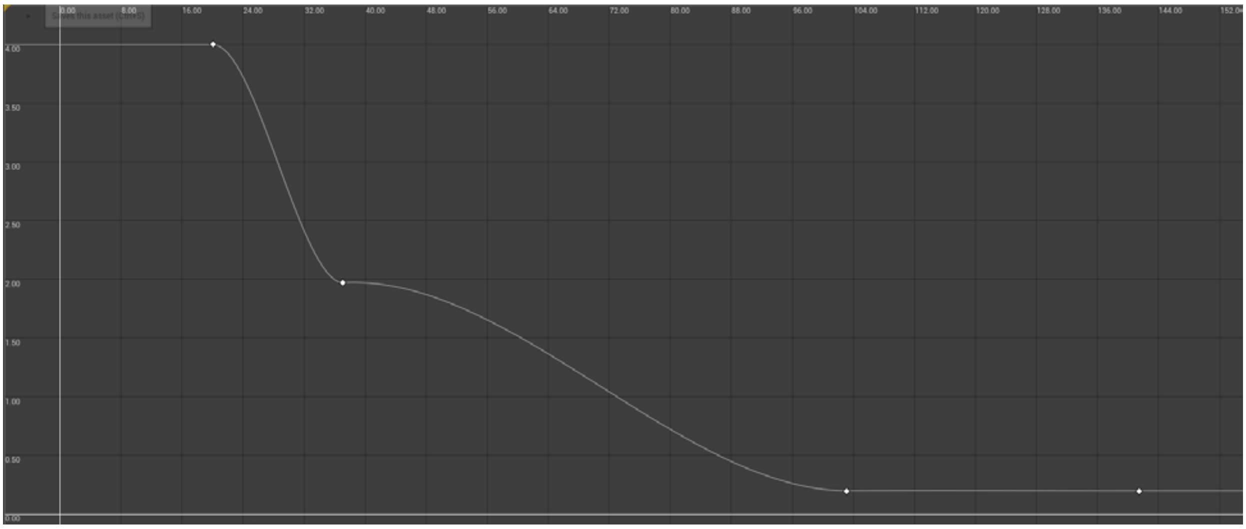


Figure F14. Importance curve for the direction towards the pedestrian, when he is opposing the robot. (x=angle, y=importance factor)

until 20 degrees is therefore relatively high: 4. Behind the robot, the importance factor is only 0.2, since the pedestrian has already passed and is walking further away from the robot. The middle section of the curve is also relatively important. If the force from pedestrians between roughly 45 degrees and 135 degrees is too high, the robot will keep a very safe distance when passing pedestrians. This will feel comfortable for that pedestrian, but with a crowded sidewalk, the robot will have trouble finding a path in which the repulsion forces will not bring him to a stop. Another negative effect is that it will move more dynamically over the sidewalk and become less predictable.

Directional importance curve for pedestrians in the same direction.
Pedestrians in the same walking direction are less of a threat to confrontations and collisions. Straight in front the importance factor is therefore 2. This is high enough so the robot will not approach too closely, but low enough, so it can follow a pedestrian walking in the same direction. Pedestrians that are walking behind the robot could run into the robot if it slows down too abruptly. Therefore, an importance factor of 0,5 still has a little effect on forces in the robot's forward direction. This only works if the robot is driving very slowly. When it reached its maximum speed, it will not go faster.

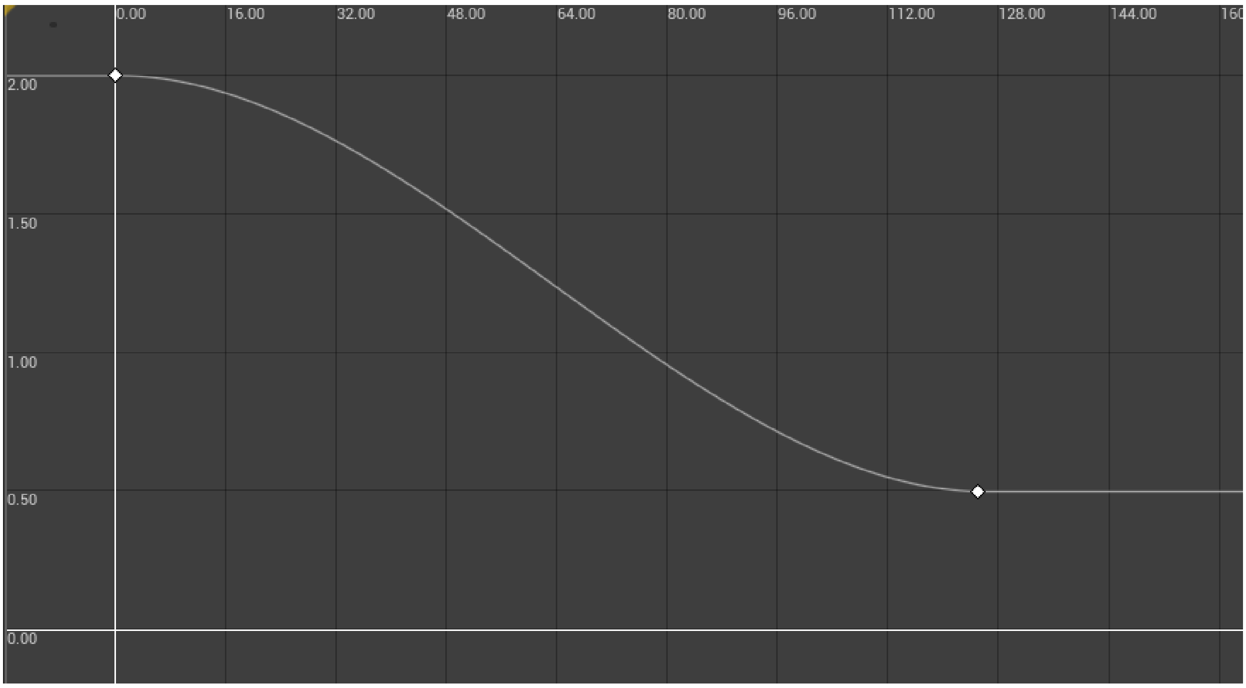


Figure F15. Importance curve for the direction to a pedestrian in the same walking direction. (x=distance, y=importance factor)

Adjusting behavior for crossing pedestrians

Due to the robot having wheels with a minimum steering angle, the reaction to the sum force is different than a pedestrian, which can move around its axis. Without any adaptations to the model, this results in unwanted behavior, when a pedestrian is crossing the robot. In figure F16, it can be seen that if a pedestrian is on the right side of the robot and moving towards the left side, the robot will move left, cutting of the crossing pedestrian. This happens because the robot only looked at the position of the pedestrian and not to its walking direction. An addition to the model is made, in which the standard angular offset of 30 degrees is turned into the opposite direction. This results in the robot turning to the other side and slowing down slightly more.

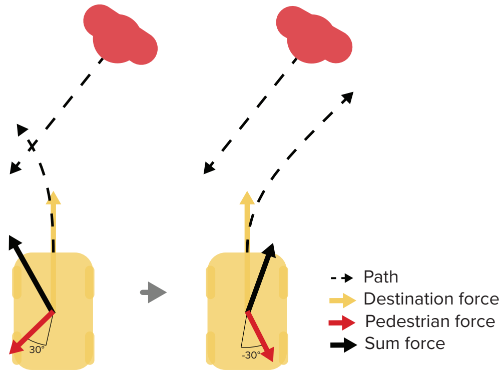
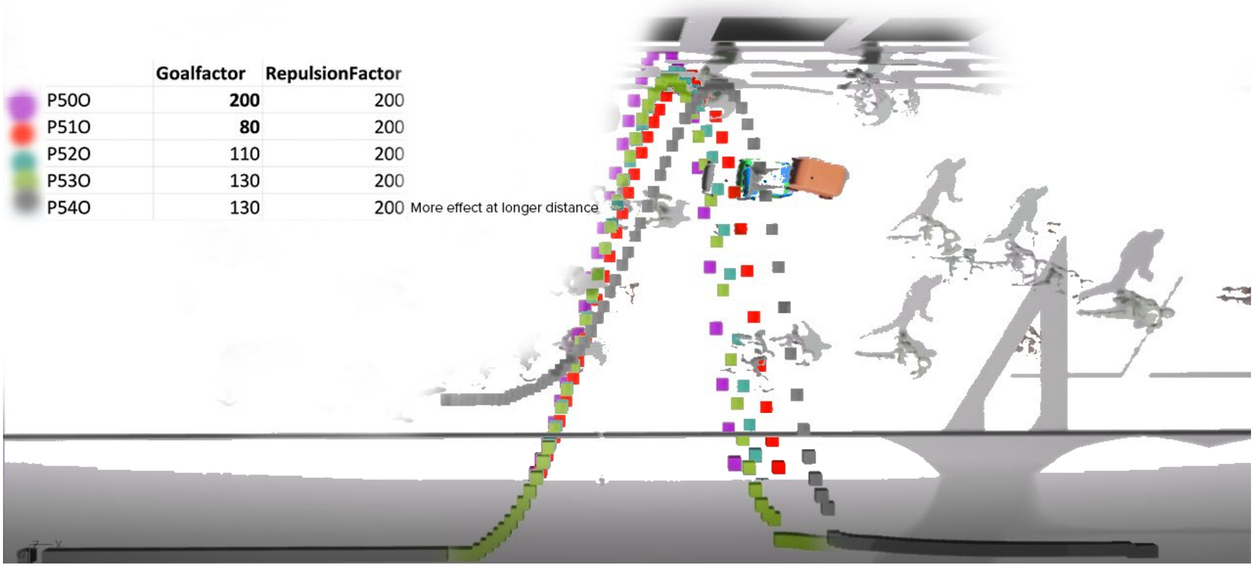


Figure F16. Crossing pedestrians negative offset.

There are a few conditions that have to be met, before the robot recognizes it as a crossing behavior. The pedestrian should be on one side, but walk towards the other side. The angle between the robot's and pedestrian's forward vector should be between 0 and 20 degrees. The pedestrian should be at an angle between 7 and 35 degrees from the robot. And finally, the pedestrian should be at least 2,5 meters away, to allow the robot enough time to go behind the pedestrian. These values were found based on the limited amount of scenarios that were tested. It is likely that with further research, these values will change and that the change in angular offset should relate to the specific circumstances.

Simulated behavior

The resulting behavior looks natural. It keeps a safe distance from pedestrians and reacts significantly early to opposing pedestrians. During optimization a balance was found between the robot's behavior in a group and minimizing the force on specific pedestrians. It was found that this balance can be hard to accomplish. Adjusting a parameter slightly to decrease the experienced force by a pedestrian, might reduce to robot's functioning in a crowd significantly. In figure F17, the force from the robot onto one pedestrian can be seen in a graph. An increase in goal factor means that the robot is going more strongly to it's final destination and therefore repulsion forces have less effect on the movement. By adjusting parameters, the peak force can be brought down, by for instance making the robot move aside earlier. However, making the robot react from too far away, will lead in problems when encountering crowds. Therefore only minor adjustments are possible. See figure F19 for a full overview of all documented adjustments. This gives insight into the process and the insights gained along the way. The test number references to the file name of the video



	Goalfactor	RepulsionFactor
P500	**200**	200
P510	**80**	200
P520	110	200
P530	130	200
P540	130	200 More effect at longer distance

Figure F17. Curve of the experienced repulsion force by one pedestrian, for slightly different parameters.

Figure F18. Screenshot from the simulations. The robot keeps enough distance when moving around pedestrians and reacts strongly enough to pedestrians in it's path. The red line represents the strength and direction of the total repulsion forces "experienced" by the robot. The grey line represents the sum force (including goal force).

Number	Goalfactor	RepulsionFactor	ObstacleFactor	Backforcefactor	Speedpreference	Other	Explanation	Result
Setting1							Initial configuration	
P1	80	200	230	0.4	0.4			Turns are wide, st
Setting2							Extra force angle to 0	
P2	80	200	230	0.4	0.4			Stands still more
Setting3							Back to extra force angle 15	
Setting4							Speedcurve more to left	
P3	80	200	230	0.4	0.4			Turns are wide, st
P4	80	**150**	230	0.4	0.4			Less standing still
P5	80	**100**	230	0.4	0.4			Takes the other si
P6	80	**50**	230	0.4	0.4			Comes too close,
Setting5							Map steering range to 0.5	
P7	80	200	230	0.4	0.4			More subtle steer
P8	80	200	230	0.4	0.4		Map steering range to 0.1	Steers very slow.
P9	80	200	230	0.4	0.4		Less steering at higher speeds	Better predictabil
P10	140	200	230	0.4	0.4		Human goal force	Better mingles in
P11	140	300	230	0.4	0.4		Repulsion force higher	Stands still too m
P12	140	300	230	0.4	0.4		More repulsion from side	
P13	140	200	230	0.4	0.4			Runs people over
P14	140	200	230	0.4	0.4		More repulsion from side	Robot oversteers
UNTILL NOW THE EFFECT OF THE BACKFORCE (ENTITIES ARE OUT OF VISION, SO LESS EFFECT) WAS NOT WORKING								
THE ROBOT STILL HAS NO REDUCED FORCES FROM THE BACK, BUT DOES REACT DIFFERENT ON ENTITIES THAT ARE MOVING IN THE SAME DIRECTION								
P15	140	200	230		0.4			Pedestrians and r
P16	140	200	230		0.4		More repulsion on opposing pedestrians	
P17	140	200	230		0.4		Pedestrians react to robot with correct back force	Way better
P18	100	200	230		0.4			Reacts more dyna
P19	70	200	230		0.4			reacts more dyna
P20	120	100	230		0.4			Not bad at all
P21	120	50	230		0.4			Very steady, but r
P22	120	200	230		0.4			Not bad at all, bu
THE ROBOT NOW TAKES INTO ACCOUNT THAT IT DOESN'T MOVE IN THE SAME DIRECTION AS YOU, WHEN IT COMES STRAIGHT FROM THE SIDE								
P23	80	200	230		0.4			Accidental trigger
P24	80	200	230		0.4		More impact closer by (was not the intention)	No effect
P25	80	200	230		0.4		More impact straight in front	Slight earlier reac
P26	80	200	230		0.4		Even more impact straight in front	No visible differer
P27	80	200	230		0.4		Less strong steering curve	More predictable
P28	80	200	230		0.4		Reverse steering strenght input	More predictable,
P29	80	200	230		0.4		Slightly stronger with small input	Better
P30	80	200	230		0.4		Opposing on left is a stronger force	Not really visible
P31	200	200	230		0.4			Didn't fix the side
P32	300	200	230		0.4			No difference visi
UNTIL NOW THE LONGER DISTANCES WERE IMPLEMENTED WRONGLY								
P33	200	200	230				More effect on longer distance. Just a slight difference.	It reacts earlier th
THE DISTANCE CURVE WAS APPARENTLY SHARED BETWEEN THE ROBOT AND THE PEDESTRIAN. SO THEY REACT SIMILARLY AT DISTANCE, BUT NOT AT ANGLE.								
P34	200	200	230				Extreme effect on longer distances	Every robot gets s
P35	200	200	230				New sidewalker setup with angle offsets	
SIDEWAYS SYSTEM WAS NOT WORKING PERFECT AND IS NOW ADJUSTED ONLY FOR PEDESTRIANS STRAIGHT IN FRONT. FROM FURTHER AWAY THERE IS AN EFFECT.								
P36	200	200	300				Sidewalker changes	
STARTING OPTIMISING FOR LOW FORCES EXPERIENCED BY PEDESTRIANS								
P37O	120	200	300				Zero test	Force quite high a
P38O	120	200	300				Turned off system for straight in front	Little higher peak
P39O	120	200	300				Side walker offset -0.75>-1,0	Higher, but wider
P40O	120	200	300				Side walker offset -0.75>-0.5	Lower but smalle
P41O	120	200	300				Adjusted trigger angle for sidewalker offset	Slight lower, but r
P42O	120	200	300				More force straight in front	Slight lower, but r
P43O	120	200	300				Extreme force stright in front	Lower, but narrow
P44O	120	200	300				Less extreme, but wider	Significant lower
P45O	120	200	300				Higher force at larger distances	Quite the same ,
P46	120	200	300				Sideways walker turned on	Adjustments of th
P47	120	200	300				Angle and distance curve adjusted	Still gets stuck.
P48	120	200	300				Distance slight adjustment	Better, just like fo
PEDESTRIAN THAT OUTPUTS DATA IS PUT INTO A CROWDED ENVIRONMENT								
P49O	120	200	300					
P50O	**200**	200	300					Higher peak and r
P51O	**80**	200	300					Wider and lower,
P52O	110	200	300					
P53O	130	200	300					
P54O	130	200	300				Pedestrians more force at distance	Pedestrians get st
P55O								
THE STEERING AND THROTTLE CURVE WERE NOT OPTIMISED. THIS RESULTED IN ABRUBT STEERING AND LESS DECCELERATION WITH MORE REPULSION FORCES.								
P56	200	200	300				Changes to output curves.	Way more subtle
P57	200	200	300				More effect at higher distance	Gets stuck and sta
P58	200	200	300				More effect at higher distance, less straight front	Quite good
P59	200	200	300				Even out middle of the angle curve	Quite good, shoul
P60	200	200	300				Increase in effect at distance	Too high of forces
P61							More effect on middle long distances, less at longer	Quite good
THE ROBOT SHOULD STEER LESS WHEN IT IS DRIVING AT HIGH SPEEDS.								
P62							At full speed, steering angle is decreased by half	Quite good, more
P63							Full speed has 0,25 steering effect	Good!
THE STEERING CURVE WAS ADJUSTED WITH THE MAXSTEERINGATSPEED CURVE. NOW STEERING CURVE IS ADJUSTED AGAIN								
P64							The robot stops only if the total force is repulsing and if it is at more than about 10	
P65							Same	
P66							More angular offset (30degrees) , more steering at high speeds	Little less stiff, bu
P67							Angular offset 25 degrees	Little more brakin
P68							Angular offset 20 degrees	Even more brakin
P69							Angular offset 35 degrees	No braking, good
P70							Angular offset 40 degrees	Still very good in t
THE OUTPUT RANGE OF THE STEERING WAS MAPPED BASED ON A CURVE. THIS CREATED AN EXPONENTIAL STEERING EFFECT AND THEREFORE LESS STEERING WITH SMALL FORCES								
P71							Steering curve was deleted	Better smaller ste
P72							More effect at longer distances	One weird turn, b
P73							Normal, low effect at distance.	Robot doesn't rea
P74							Lower force for pedestrians walking in the same direction	The current scena

Figure F19. Experimental process of changing parameters and iterating to desired behavior.

	General discussion
tands still quite often	
often	
tands still quite often	
l	
ide, more dominant	The robot is just as likely to go left as right > change to prefered right
but less dynamic with steering (better)	
ring?	
Stops very often. No success	
ity at higher speeds	
with other pedestrians.	Should have more repulsion from the side
uch	Should turn already when someone is approachin straight , but far away
	He can cut people off if they are walking just behind him
	There is a difference between the side forces when going in the same direction and the opposite direction
obot now react different. Robot comes to close, with opposing people	
	The robot should be a little more predictable
amic, slower	
mic, slower, problem with one pedestrian	
uns you over	
t too unpredictable	
r of sidewalking person	
ction	
nce with P25	
behavior	Still reacts strong to opposing entities that are clearly to the side
, but not strong enough far away	This and the distance curve, are having the same function. So this one could be constant.
ways walker problem. More predictable movement	
ble	
han pedestrians. Which makes it cut them off sometimes.	The robot should be more aware of the walking direction of people. It seems that the effect on longer distances should be the same as with pedestrians.
tuck at long differences. The amount of available space decreases.	
nd with a peak	
.	
peak	
r peak. Sidewalk crossing was working, so force on robot was offset.	Sidewalk crossing should be enabled only above eg. 5 degrees.
narrower	
narrower	
ver	
curve	
low, but little wider	When optimising, more space towards the robot is better, but will not work in complex environments
he optimalisation make it disfunctional. Repulsion forces get too high.	
r force optimalisation	
	More impact at longer distances, really affects the performance in crowds.
arrower	
but robot gets stuck	Robot decellerating does not decrease the height of the curve much, compared to moving aside.
	What if pedestrians react slightly earlier than the robot?
	Ratio of 120:200 (goal:repulsion) seems the best for robot level of initiative
tuck. Sudden force jump, but no lower peak	
steering, but still a bit too late.	
arts turning circles	
d still react earlier	
s with multiple entities	
fluent	
	The height of the repulsion forces peaks, determine how fast it will brake for pedestrians.
0 degrees	
ut still very predictable.	**More angular offset is less braking, more steering**
g.	
g	
steering	
this scenario	Speed keeps on higher, which limits the steering. More angular force therefore doesn't mean much more steering
eering movements. But a bit too dynamic maybe.	
ut furthermore the same.	Force can better be gradually increasing. So back to the previous setting.
lly know what to do if two pedestrians are crossing it at the same angle and distance.	
rio's are less influenced, but it should be more in balance.	

Discussion

Although that multiple articles from literature were reviewed about the social forces model. The implemented model is an interpretation of the overall principle behind them. The original formulas are not copied but implemented in such a way that it creates the freedom to quickly adjust the robot's behavior by changing a parameter or changing the shape of an importance curve. More research should be done to review all social forces models in literature and implement proven equations into a simulation. This will likely result in some fundamental changes in the setup of the forces. An example could be that some literature describes how the elliptical forcefields around pedestrians act on each other, which provides the location, direction and strength of the force. This could take into account more the walking direction of pedestrians. This is in contrast with the model in this project, in which the actual position of other entities is used and therefore, only personal walking direction is taken into account and not the walking direction of other pedestrians.

The parameters of the model and the "angle curves" and "distance curves" were found by trial-and-error. Based on personal insight, they were optimized for realistic pedestrian behavior. There will need to be more optimization done, to find the perfect values and for a larger variety of scenarios.

A larger variety of scenarios should be tested. The focus of these simulations was on optimizing the robot's behavior on a sidewalk where all pedestrians have a destination which is at the end of the sidewalk. Therefore, no optimization was done on pedestrians walking perpendicular to the robot. A challenge that will arise is visible in figure F20. The scenario is similar to the earlier described challenge where the pedestrian is walking at an angle towards the robot and is crossing to the other side, but now with a more perpendicular motion. The model should be adapted, so that the robot will notice this behavior and react by stopping, going behind the pedestrian or speeding up and move alongside.

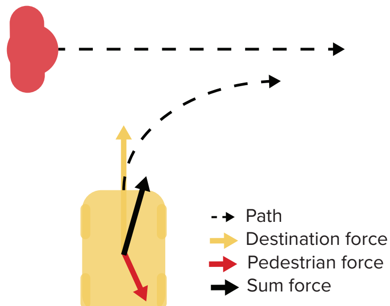


Figure F20. Perpendicular pedestrian challenge.

Other scenarios which are not taken into account with these simulations are:

- Significantly faster or slower walking pedestrians.
- Different pedestrian personalities that experience larger or smaller repulsion forces.
- Robot behavior when overtaking slower walking pedestrians.
- Pedestrians that unexpectedly change their goal destination.
- Very narrow sidewalks

It should also be taken into account that it is not researched yet, how pedestrians react to robots compared to other pedestrians. They might experience more repelling forces, because it is an unfamiliar entity. But the opposite is also possible: less repelling forces, because it is not a human with a personal zone that you can get into. Different pedestrian personalities will react differently to the robot. For instance, elderly, which might be more cautious towards the robot. Or children, which might jump in front of the robot and start playing with it.

The robot is sensing pedestrians in a range of 5,5 meters. It also senses pedestrians that might be out of view. In this simulation, this effect will be minimal, since the repulsion force at that distance is minimal. There is the possibility to add extra logic, in which the robot can take into account these pedestrians in its planning.

In general the robot manages to reach its goal destination without problems. However, there are still scenarios in which the robot has trouble finding it's way. For instance when it is very crowded and there are much forces acting on the robot. In that case it might slow down or stop. Another issue with the model is that it does not look at the consequences of the robot's decision. If the robot moves out of the way for a pedestrian and as a result is opposing another pedestrian, it might not have the time to steer back. This could result in the problem in figure F21, in which a front of pedestrians on one side, pushes the robot all the way sideways. These examples of challenges should all be solvable by adjusting the social forces model.

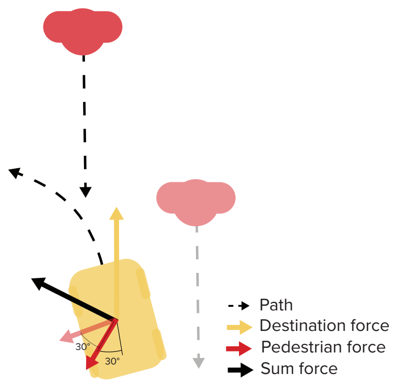


Figure F21. Continuing a suboptimal path.

Conclusion

The final result is a robot behavior, which is optimized based on it's visual applicability to the different situations and by decreasing the forces experienced by one participant. The robot moves natural, predictable and safe in scenarios for which it is designed. The research showed that there are however a vast amount of scenarios in which the current parameters don't function properly. This could be assigned to the robot having a steering radius instead of a pivoting movement. The effect of this difference should be researched more for a wide variety of scenarios. In general further optimization and balancing out of forces, could make the robot function better in changing scenarios.

A large benefit is that the social forces model is inherently connected to human behavior. Current delivery robots might rely more on keeping a straight path and expect pedestrians to adapt. The turning behavior of these robots are not inherently human, which makes them feel less familiar and more unpredictable. The social forces model has the potential to solve this. Although pedestrians will not be aware of this difference in programming, after a few encounters with the robot, they will get used to it's behavior and will feel in control on their sidewalks.

Implementing a social forces model into a physical robot that performs well in all scenarios, will be a challenging task. However, this is just as much the case for other ways of programming the robot. The benefit of applying the social forces model is that it has the potential to solve most of the scenarios with the same piece of code. Furthermore, there are additional potentials. By inputting positional information, the model can make short term predictions about what pedestrians are going to do, or how crowds will behave. The model also provides the opportunity to optimize interactions based on quantitative data. Interactions will be more comfortable for pedestrians, if the social forces they experience are lower. A machine learning algorithm could be implemented on top of the simulations, to find optimal parameters that achieve maximum comfort. Also in real-life the robot could calculate the forces that pedestrians experience. In figure F22 for instance, a pedestrian experiencing high repulsion forces from obstacles and the robot. The robot could make space for that pedestrian, while taking into account the extra forces that it might generate on other pedestrians.

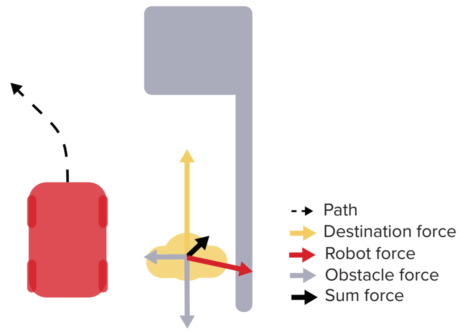


Figure F22. Decreasing repulsion forces experienced by pedestrians.

Above some opportunities are explained to use the social forces model in a non-standard way, to increase interactions on the sidewalk. This means that the robot should be able to take initiative in interactions, if it knows that it has found the optimal way of increasing everyone's comfort. This initiative can be taken by communicating the intended path earlier than pedestrians do. Figure F23 describes the use of initiative and it's potential effect on the interaction.

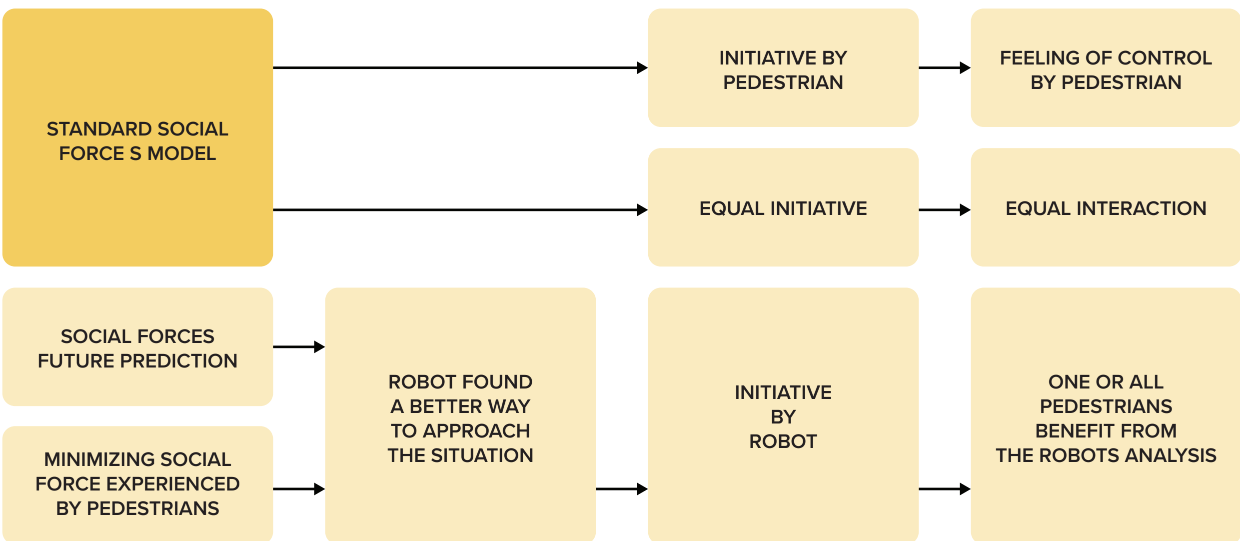


Figure F23. The role of taking initiative in creating optimal scenarios.

Based on this research, the reaction time should be very similar to that of pedestrians. This creates an equal importance on the sidewalk. There is a possibility to make the robot react slightly later than pedestrians. In this situation, the robot is reactive to pedestrians and has therefore limited opportunity to take into account the effect of its future path. The positive effect of pedestrian initiative is that the feeling of control by that pedestrian might grow, since he has the power to decide how the interaction will go. The last possibility is to make the robot react earlier than pedestrians. This could be implemented if the robot has sensed that this decision will increase the comfort for some pedestrians and doesn't endanger the comfort of others. The result of this early initiative by the robot is that all pedestrians could benefit from better interactions, because of the robot's analysis.

In general, how early the robot reacts to opposing pedestrians is one of the most important parts of the robot's behavior. Pedestrians have the habit to communicate their intended direction very early. Especially on empty sidewalks, this decision, or negotiation with another pedestrian, could already be at 10 meters apart. At those distances, the social forces model will not function. An adaptation to the model should be made, like a very strong effect on long distances, when there are very few pedestrians. Or the robot could always have the bias to stay to the right.

Social forces and cues user test
Appendix G

Goal of the test
The insights from the first user experience test gave much insights, which made the design of the robot change slightly and the interaction majorly. For the behavior it was assumed that a robot operating with a social forces logic feels more familiar and more comfortable to interact with. This is tested within this user experience test. Straightforward scenarios are tested, in which the robot operates based on social forces. The goal is to see if pedestrians prefer a robot which keeps a straight line, or the designed behavior, or a more dynamic behavior. A separate scenario tests the special indicators, namely the blinking light on the front, the pivoting of the body and the lights on the bottom. To validate if the appearance of the robot is having the intended effect on pedestrians, a benchmark test is done to see how acceptable it is compared to other delivery robots.

Research questions
- How acceptable is the robot compared to other delivery robots?
- How predictable is the behavior when people first encounter the robot?
- What robot behavior makes people feel the safest?
- How do the special indicators influence the predictability of the robot?

Test setup
Benchmarking appearance
The card desk that was used for the “pedestrian interviews” is used again to benchmark the robot compared to other robots. The participants are asked to rank the delivery robots from what the prefer least, till what they prefer the most, to come across on the sidewalk. After the participant has put the robots in order, it is asked what the criteria they used.

Figure G1. Card desk with the different robots.

Social forces behavior
To test how the behavior of the robot is perceived, a virtual environment is set up. Pedestrians are walking in two direction, to create a more complex scenario for the robot. The robot is moving in the direction of the participant, which is standing still with a VR-headset and is observing the behaviors. Both the robot and the pedestrians can sense the presence of the participant and will adapt their path based on social forces.

Three different scenarios were tested.
Scenario 1: The robot brakes based on the designed social forces behavior, but keeps a straight line. This is the most machine-like robot.
Scenario 2: The current design of the behavior, with a robot which participates in the flow if pedestrians, but is not too dynamic and unpredictable.
Scenario 3: A more dynamic version of the robot which steers much also at high speeds.

After each scenario the participants are asked a few questions about how they experienced the scenario.

* I felt safe at all times.

Strongly disagree			Neutral			Strongly agree

* The behavior of the robot felt predictable.

Strongly disagree			Neutral			Strongly agree

* The behavior of the robot felt similar to how humans behave.

Strongly disagree			Neutral			Strongly agree

* The robot adapts itself to the pedestrians.

Strongly disagree			Neutral			Strongly agree

* What do you think of how the robot behaved?

....

After all three social forces scenarios:

* Which one of the three robots would you prefer to encounter in real life? Why?

....

In scenario 4 the special indicators are tested. The scenario plays in a night setting to better see the lights, especially the lights on the bottom of the robot. There are very few pedestrians in the environment, since the robot moves on a preprogrammed path, instead of social forces. The robot moves towards the participant. It will indicate that it will take a turn to its right by slightly moving its body in that direction and blinking with its indicator. Before taking a stop, the robot will lean forward and the lights on the bottom will turn red. After a few seconds, the robot leans back, the lights on the bottom turn white again and the robot will start driving. It then leans left and blinks with its indicator, before taking a left turn again. The participants are then asked a few questions about how they experienced the scenario.

---

* The behavior of the robot felt predictable.

Strongly disagree			Neutral			Strongly agree

* What did you see that the robot did and communicate?

....

- At what point did you notice that the robot was about to stop/turn?

....

- What cues or characteristics made clear to you what the robot was about to turn?

....

- What cues or characteristics made clear to you what the robot was about to stop?

....

- What cues or characteristics made clear to you what the robot was about to accelerate?

....

The final scenario is to experimentally test if the final behavior design is perceived differently when the participant can move around, instead of standing still. In the limited space available he can move a few steps in all directions. In the scenario the robot reacts to the position of the participant, however, the other pedestrians do not. In a rare occasion, a pedestrian could hit the participant. Since this scenario is always tested as last part of the test, there will be a learning effect. The exact same questions will be asked as with the first three scenarios.

Results

Since the test was partly qualitative, below the statements of the participants, per scenario, is transcribed.

Participant 1

Scenario 3: The robot had some unpredictable behavior, in that it was expected that he would go to the other side of a pedestrian.
Scenario 1: Now the eyes are perceived, they go back and forth.
Scenario 2: It looks like the robot deviates a little earlier. This makes him look more “searching”. He reacts a bit too extreme. The participant would still move around the robot, like with pedestrians.
The robot moving in one straight line is the best, it feels the most decisive. Scenario 2 reacts a bit too late.
Scenario 4: The lights on the bottom were perceived, however the turning not. The robot showed a red light indicating braking and white for driving. This was perceived slightly before the robot actually performed the action. The eyes might have showed that it was about to turn. The red and white lights on the bottom are clearly for stopping and accelerating.
Scenario 5: The robot moving around me felt like a rejection. There was enough distance between me and the robot. He also reacted adequate. He seems to be agile enough.
Post scenarios: The robot could have more indication for when it will turn. However, like with scenario 2, there is no indication needed. It seems that the eyes communicate something, but it is more likely that they scan the environment. The eyes make him more friendly, less anonymous and give him more character.

The participant would accept the robot if the sidewalk is wide enough. Elderly, strollers and robots should manage to pass each other. The participant thinks it is important that the robot is efficient, that it can carry enough parcels. Otherwise, you need way too much robots.

Participant 2

Scenario 1: The robot will not move to the side. The initiative is with the pedestrians, but that is not a bad thing, because he is not driving fast and with normal postal guys you also move around them.
Scenario 2: The robot is more subordinate, seems safe, but not really human-like. This might become an issue when it is very crowded. Since the robot moves a lot, it becomes more unpredictable.
Scenario 3: The robot seems very searching. If there is no one in front of him, he will already start turning. The eyes make him more insecure, he doesn't know what to do. The robot moving in one straight line is the most trustworthy, it doesn't have to be human. The moving eyes and blinking are a bit too much, trust decreases.
Scenario 4: It was clear that the robot was about to brake, but not that it was about to turn. Braking was early visible, because of the red bottom lights. You would expect the lights to be on the front and bottom, not necessarily on the bottom.
Scenario 5: The robot was already turning around me, so a reaction on my movement was not visible.
Post scenarios: The lights on the bottom made him more predictable. Also that he brakes early makes clear that he has seen you. The pivoting to the front and back is playful, but not really necessary. The movement of the eyes make him doubtful, especially with blinking while turning. The eyes should also look in the direction in which it is going. The participant would accept these robots, they would fit. But personal communication is not necessary, it could stay functional. In general the design is nice, neutral, trustworthy, sound, nice color.

Participant 3

Criteria for the benchmarking are how they look, especially their size, weird shapes are not good and how they are expected to move.
Scenario 2: He doesn't drive fast, so feels safe. It was looking around, like it was paying attention. The robot deviates far ahead.
Scenario 1: It didn't seem to pay attention to the environment. It is not threatening. You can just go around it.
Scenario 3: He moves jerky and comes too close. He has no control over it's movement, which makes him look unstable. The pedestrians don't have to move away from him.
Scenario 4: The robot moved away for the pedestrian that was approaching and looked at him. It was not clear why the robot had to stop. The lights on the bottom and leaning was perceived at the moment when it braked.
Scenario 5: There was no reaction from the robot visible.
Post scenarios: How the robot moved from a distance and moved around people made him predictable. As well that it looked at it's surroundings. The eyes are an added value. If the robot is not to big (like this) than the participant would accept it. Otherwise it is too much and too dangerous. The robot could have some sound to estimate it's distance.

Participant 4

Criteria are how normal or strange it feels. The participant doesn't want any Black Mirror references. Technology should be serving people, instead of being on itself. The robot should look appealing. It should be efficient, so you don't need much of them, but not too large either.
Scenario 3: The robot moves calmly, so it feels safe and not threatening. It is mostly standing on itself, instead of serving.
Scenario 1: It feels less predictable compared with the dynamic robot. The robot looks a bit ignorant.
Scenario 2: There was no difference visible with the one in scenario 3. The eyes are unpredictable. The eyes make the robot behave more human, as well as the maneuvering.
The robot going straight is the least preferred. The others are more intuitive understandable. The more human, the more dominance by technology. A full AI would not be preferred, but that the robot is cute also has something.
Scenario 4: The robot shied away from human contact, which was visible by the eyes and the turning. The robot sensed the presence of pedestrians. On the moment itself, leaning and lights was seen. Red light for braking and white for accelerating. No turning cue was seen. The robot seemed to gain speed while turning. The pivoting of the body is a bit too much.
Scenario 5: Walking around in the simulation makes it more realistic. However, it makes it harder to keep an overview.
Post scenarios: The constant influence of the environment on the robot's behavior, made it predictable. As well as the movements which are not abrupt. They eyes are limitedly positive. Static would be better. You need to get used to them, then they might be cooler. The participant would prefer that the robots are not implemented. It will become a hassle. The robot looks slick, headlights are looking good, quite modern, not to futuristic and a good kind of simple. Human-like tech creates dehumanization. It's a kind of suedo humanness, which is manipulative, to gain acceptance. Like with smartphones, which are manipulating while they have negative effects on us.

Participant 5

The legs of the continental robot are scary. A more human robot is better. It is also better if you can see what the device is for, so a well visible logo is good. Eyes implicate intelligence. The Starship robot could be a good middle way, since it has the implication of eyes.
Scenario 2: The robot looks cute, timid (positive), drives non-threatening. The maneuvering still feels unpredictable. Straight line might be better.
Scenario 1: Straight line feels good. The robot reacts very late to pedestrians.
Scenario 3: Seems to steer into the direction of the pedestrian, while the path was clear. The dynamic robots should stick more to their path.
Scenario 4: It took a very wide path. Red lights were visible, after it stopped. It doesn't look like braking lights and gives more of an emergency/distressed look.
Scenario 5: -
Post scenarios: Eyes gave the feeling of predictability, but are seen more unconsciously. The robot looks a bit timid, which is positive, but it might not be able to defend itself. The design is definitely in the right direction, it is not too cute.

Participant 6

The continental robot looks kind of naked, therefore dangerous. The printer is clumsy and not advanced. The wheels of the PostMates give an advanced look. Size is important, as well as a simple aesthetic.
Scenario 3: It has a calm pace. Since you are standing still it gives a different perspective than when walking. It clearly didn't hit anyone.
Scenario 2: It seemed to react later than scenario 3, which is not really convenient. It might have been going slower than the last one.
Scenario 1: The eyes were now clearly visible.
Scenario 4: The robot deviated away from the pedestrian on the right. The eyes seeing him made that clear. The lights on the bottom for braking and accelerating. Also pivot when accelerating was seen.
Scenario 5: The participant didn't perceive that the robot reacted, because it already deviated. The robot missed a signal that it was getting close. The robot's eyes, combined with steering could make that it doesn't see you.
Post scenarios: The eyes and the lights made the robot predictable. The eyes seemed to be looking around into the environment. It made it look human and friendly. The participant would accept these robots if they drive this slowly. The robot had a consistent speed. Maybe it needs to go slower or faster on busy sidewalks. Like on a wide sidewalk, it should be allowed to go faster, but it would become more unpredictable, like a Segway.

Participant 7

Hidden wheels seem more sophisticated.
Scenario 1: The robot is slow, calm and forms no risk.
Scenario 2: It is quite similar as the last scenario. The participant was a bit surprised about the changing movement and the eyes. The eyes are searching/paying attention. This is a risk free robot.
Scenario 3: The behavior is a bit like a drunk person. The movement should show smartness.
Scenario 4: The height of the robot changed. It also seemed to go faster in the corner. The red was seen as indicator for braking, but white not for acceleration. The eyes looked at the participant and recognized her. The eyes give a sense of intelligence. This scenario is safe and predictable.
Scenario 5: The robot clearly reacted, quite early. The robot was more in control as the other ones.
Post scenarios: The lights on the bottom and the fact that it changes movement when it has seen you make the robot predictable. The eyes give a sense that it is under control over itself. The participant would want these robots in busy cities. Like strollers they can be irritating. The robot could get some sound, could be verbally saying hello or a sound effect. It could also have a nice smell. The wheels could be integrated more. A smiley would make him more happy and human.

Participant 8:

Criteria for benchmarking are that it has more personality, a known and positive brand association, more high-tech (might be only fun in the short term), good aesthetics with good detailing.
Scenario 2: As pedestrian you still need to decelerate otherwise the robot approaches too closely.
Scenario 3: The robot seemed scared, due to its abrupt movement and late reactions. The previous scenario was better. This one seemed less at ease.
Scenario 1: The robot is more dominant. It doesn't go away for you. The robot hit a pedestrian (while actually the pedestrian hit the robot). Scenario 2 is the best, since it deviated calm and beautifully. The robot in scenario 3 seemed underdeveloped.
Scenario 4: The robot suddenly stopped and turned red. Did something went wrong? The robot leaned forward when braking. Bottom lights were good indicator for braking and accelerating. The red light was scary like a terminator.
Scenario 5: The robot almost hit the participant when he made a sudden step to the side. The participant blamed the robot.
Post scenarios: The calm turns made it predictable, as well as the eyes. The robot looked in the direction where it was going, but it should be more visible. The eyes are funny, they might blink more. Blinking should be faster, like a human. The participant would accept them, because they drove fine. The robot should indicate better that it is about to stop an maybe even why it stopped. It could have a sound effect when stopping or accelerating. This could also be good for visually impaired people. The wheels could be larger and more robust.

Overall benchmarking
As can be seen in figure G2, there is the same split visible as with the ranking in the "pedestrian interviews", with robots ranked in the mid-range and some robots ranked significantly higher. The concept design is ranked within this higher category, scoring in between the PostMates and the Starship robot.

Figure G2. Ranking of the robots by the participants, including the concept design.

Perception of robot behavior
How the robots' behavior was perceived by the pedestrians can be seen in figure G3. The final behavior design scored the highest on experienced feeling of safety. The more dynamic robot from scenario 3 scores slightly lower, followed by the static robot. However, this does not mean that the designed behavior is also the most predictable. The static robot is seen as most predictable, followed by the design and thereafter the dynamic robot. However, in the scenario were the participant could move around, the designed robot was seen as more predictable than the static robot. The designed robot behavior adapts the most to pedestrians and the static robot the least.

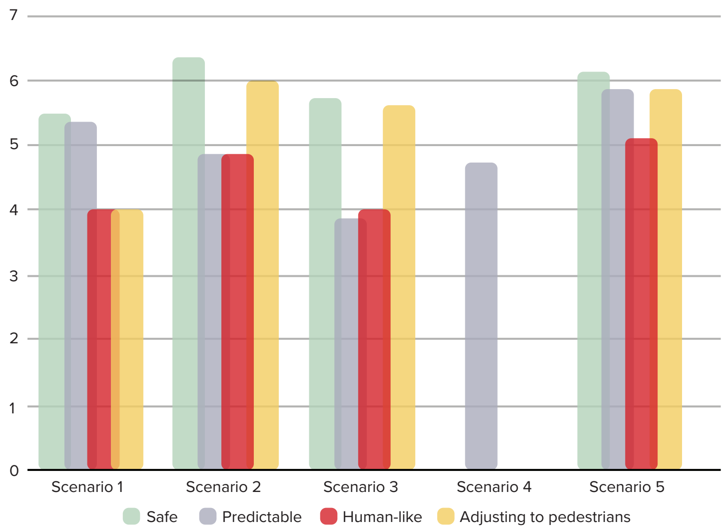


Figure G3. The average score of the scenarios on four Likert scales.

Discussion
The appearance benchmarking is only based on one image of the formgiving and not on the interaction. Participants might pick robots that seem more fun, instead of that robots that don't bother them over longer periods of time. Also the specific image chosen will have an influence. The concept design was rendered, were all other robots were photographed. The render was not of high-quality and it is likely that the participants noticed that this was the concept design.

The participants had to state how human-like they experienced the movement of the different robots. This was seen as a hard to answer question. They see the robot as a machine and expect it to move like it. Participants don't know to what human behavior they should compare it with. Most answers might have referenced to the behavior of the eyes and not to the maneuvering of the robot. Therefore, this question could better be left out of analysis.

The participants had to indicate how safe they felt throughout the scenario. This might have been influenced by the simulated pedestrians walking around. The basic Unreal Engine 4 mannequin was used, which is a broad shouldered figure with an aggressive movement pattern.

It was decided beforehand that the participants should have an observing function in the first three scenarios. This makes the test more controlled, since the decision of the participant will not influence the scenario and therefore the test results. The results of the scenarios can now be better compared with each other. However, the feeling of actually participating in the environment is lost, which gives a feeling of control and safeness.

In scenario 5 the participants were able to walk around, this changes the way of participating and can therefore not be compared well with the other scenarios. Another reason is that there is a learning effect visible. The robot is now for instance seen as more predictable than with scenario 2. The participants did already get used to the behavior of the robot.

In scenario 4 the participants had to observe different indicators. The subtle leaning of the robot was tested at the same time as the lights on the bottom. This is how the robot is currently designed, in which small cues on top of each other make the robot more predictable. However, it is very likely that on first encounter you only notice the more obvious lights on the bottom. It was not tested if pivoting of the body is a cue which is helpful over time.

Conclusion

To conclude this user experience test, the research questions are answered.

How acceptable is the robot compared to other delivery robots?
The concept design scored better on acceptance than the PostMates robot and lower than the Starship robot, based on its appearance. The robot is seen as kind with a simple design. In agreement with the other user test, people would in general accept the robots, except in certain scenarios like busy streets or narrow sidewalks. The robot should not be in the way too much. One important aspect for acceptance is the design of the eyes. Some participants saw it as an added value and it gives the feeling that the robot is sensing the environment. However, there were multiple participants that expressed that it was too much for them. It is not necessary and the robot could better have more business-like static eyes.

How predictable is the behavior when people first encounter the robot?
The designed behavior of the robot is seen as less predictable than a robot which is very static in its movements. This can be explained by the expectations that they might have of robots. Robots often move more mechanical. At first encounter the robot doesn't meet this expectation and is therefore seen as less predictable. If the robot becomes more predictable over time, should be researched further. In the last scenario, which had the same robot behavior as the earlier tested scenario 2, the participants experienced the robot as significantly more predictable than scenario 2 and even the static robot of scenario 1. This learning effect could be similar in real life.

What robot behavior makes people feel the safest?
The designed robot behavior was seen as more safe than the static robot and the dynamic robot. In general, all robots scored high on safety. This result is a good indicator that the robot has the potential to also be perceived as safe in real life.

How do the special indicators influence the predictability of the robot?
The red lights on the bottom are very clearly visible, especially when it is dark outside. Since the robot was braking after that, the two were easily associated with each other. In the long term, pedestrians will be able to predict that the robot is about to stop. The red lights can have the meaning of braking lights, however, due to the unexpected position of the lights, their meaning could also change into emergency lights. Due to the intensity some people will see the lights as a signal that something is wrong with the robot. A redesign should be made with less intense lighting, a different color or a smoother animation. There are no significant results on how the pivoting of the robot makes it more predictable. In general, most people don't notice it at first encounter. Some people that did notice it, saw it as playful, but also too dramatic. This can be explained by the pivot, which is not only performed earlier than the natural pivot, but also making the natural pivot more dramatic. As a recommendation, the pivot should only be performed early, but not increasing the overall intensity of the pivot.

Other insights
All participants noticed the eyes which were moving around. They assigned different functions to them. Often it was seen as perceiving the environment, but some participants thought it was looking in the direction in which it was going. For the later, it didn't seem to cause significant confusion.

The eyes also did cause difference in the meaning that was assigned to them. Due to the increased humanness that is induced by the eyes, the anthropomorphizing effect increases. People will assign emotions to the robot. So although the eyes could move quite neutrally, if the robot maneuvers around in an insecure way, the eyes that look around are also seen as insecure. As if he is looking at the environment, not knowing what to do. First of all, the maneuvering of the robot should already look confident and this should be matching with neutral eyes or eyes that also give a sense of confidence. The effect of eye animations should be researched further, to understand their effect on perception.

Since scenario 4 had a very basic preprogrammed movement. Some participants noticed the difference between the social forces model and the behavior in scenario 4. This robot didn't decreased it's speed before turning. Since normal vehicles always do this, the behavior was even perceived as an acceleration while turning. The social forces model automatically regulates this deceleration before turning, due to the length of the sum force being smaller when opposing forces are acting on the robot.

In this test it became clear that the social forces model could be optimized further. The robot was adapting significantly to the pedestrians. Due to the offset angle of 30 degrees, compared to the pedestrians offset angle of 15 degrees, the robot deviated more than the pedestrians. The maneuvering of the robot might be more predictable if it is slightly less subordinate and a little more keeping a straight line. This would result in a more equal interaction between robot and pedestrian.