Are we roboready?

Developing a method to determine the roboreadiness of a traffic environment

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by

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Preface

Are we roboready? Trying to answer this question would not fit into one thesis. There are so many interesting research opportunities about delivery robots, of which this thesis only considers the traffic environment. Looking into the future, I think delivery robots will become part of our city logistics. It could support the goods transportation in urban areas, but not as the only delivery option. The efficiency, in case of the sidewalk delivery robot, is low since only one order at a time can be delivered. At the moment, the biggest resistance is legislation and regulation. If this were not an issue, I think delivery robots would soon be on the road. It could be a good solution to the shortage of personnel and the upcoming ageing population.

This thesis marks the end of my time in Delft, where I followed the master Transport, Infrastructure and Logistics. With the topic about delivery robots in the spatial context, my two main interests being mobility and logistics, could be combined.

I would like to thank The Future Mobility Network for the opportunity to use the pilot with Rosie at the campus of the Erasmus University Rotterdam for my research. I enjoyed spending time at the campus, where I studied during my bachelor, performing test runs and observing Rosie's operation.

Furthermore, I would like to thank everyone who helped me in the process of writing this thesis. I am glad that my friends and I were in the same stage of study and that they could keep me motivated in challenging times. In particular, I want to thank my graduation committee consisting of Tim Klein, Arjan van Binsbergen, Ron van Duin and Lóri Tavasszy, for all the interesting ideas and valuable feedback.

Emma Arntz
Delft, August 2022

Summary

Context

In the world of today, everything has to be better, faster and more sustainable. There is a search for alternative ways of allowing processes to take place without human intervention. By using smart systems based on new technologies, logistical tasks can be automated which improves efficiency and performance (Jagtap et al., 2020). The last-mile logistics could benefit from this, since this step is the least efficient within supply chains (Ranieri, Digiesi, Silvestri, & Roccotelli, 2018). In addition, the last-mile delivery faces multiple challenges, like urbanisation and the shortage of staff partly due to ageing. Therefore, innovative delivery concepts are desirable. The expectation is that 80% of all business to customer deliveries will be delivered autonomously in the future (Joerss, Schröder, Neuhaus, Klink, & Mann, 2016).

Current literature on the topic of self-driving delivery vehicles shows that automation in last-mile logistics could lead to cost and time reduction and can provide a sustainable way of delivering goods (Chen, Demir, Huang, & Qiu, 2021; Figliozzi & Jennings, 2020; Lemardelé, Estrada, Pagès, & Bachofner, 2021). However, there is a need for more research on the integration of these delivery robots in the public space. Since the delivery robot is a relatively new concept, the research area is growing and not yet mature. This could be the reason that last-mile delivery concepts lack theoretical perspective (Boysen, Fedtke, & Schwerdfeger, 2020; Olsson, Hellström, & Pålsson, 2019). In order to contribute to the theory building, this research aims to propose a methodology that can be applied to determine the 'roboreadiness' of a traffic environment. This expresses whether the environment is ready for delivery robots to drive there. This should answer the main research question:

"How can the roboreadiness of a traffic environment be determined?"

Delivery robots have to deal with a lot of robot-environment and human-robot interaction. This makes that the success of the implementation depends on the performance of the robot and whether people are prepared to interact with it, in the given traffic environment. This research focuses on active modes traffic environments, since the empirical validation is performed at the campus of the Erasmus University Rotterdam.

Methodology

The aim of this research is to develop a method in order to determine the roboreadiness of a traffic environment, by assessing the performance of the robot and the level of social acceptance. These topics are explored and examined in two phases. The first phase includes the desk research, in which a literature review is performed. Since scientific literature on delivery robots in the spatial context is scarce, articles about the performance of new transport concepts and the acceptance of technology innovations are reviewed. The acquired knowledge is used to create a conceptual model, presenting the relations between the elements and showing the influencing factors.

The second phase is the development of the assessment method, which makes it possible to measure the level of roboreadiness of a traffic environment. The development of the assessment method is divided into the set-up, the method itself and the validation of the method. In the set-up, the goal and objectives of the method are described, discussing the conditions to be met for executing the method. The assessment method itself consists of two parts: a test-case, to measure the performance of the delivery robot in its traffic environment, and a survey, to determine the level of acceptance in relation to the traffic environment. All steps to be taken to come to the level of roboreadiness of the traffic environment are elaborated in this stage. To validate the method, the traffic environment at the campus of the Erasmus University Rotterdam is examined.

Findings

During desk research the factors determining performance and the factors determining social acceptance are identified. Putting this in the context of delivery robots in the traffic environment, the performance factors are defined as ‘pace’, ‘continuity’, ‘deviation’, ‘safety’ and ‘compliance’. The factors influencing the social acceptance of delivery robots in the traffic environment are ‘predictability’, ‘competence’, ‘comfort’ and ‘dimensions’. The elements and factors have been converted into a conceptual model, presented in Figure 1. These factors have to be assessed in order to determine the level of roboreadiness of a traffic environment. Hence, the conceptual model serves as a starting point for the selection of the sub-methods in the assessment method.

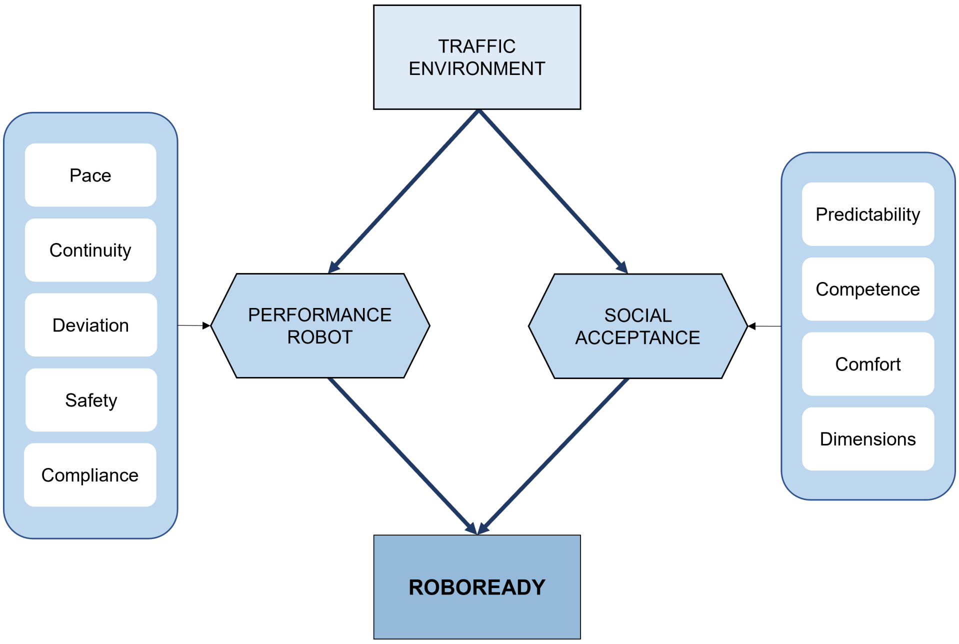

Figure 1: Conceptual model of the factors influencing the roboreadiness.

The level of performance and level of social acceptance are to be determined per setting. Therefore, the traffic environment first has to be divided into static settings, used within the traffic scenarios. Then, in the test-case the performance factors have to be assessed per scenario. This is done based on observations. In the survey, the social acceptance factors are to be assessed. This is done by questioning respondents (people who are walking in the same traffic environment as the delivery robot) to weigh and score the indicators in each scenario. This represents the importance of the factors in determining the social acceptance, in the scenario.

The results that have been obtained by performing the two sub-methods are to be analysed. A statistical analysis should be carried out on the data, whereafter these are interpreted. In this way, the level of performance can be determined per setting. The different levels are: good, sufficient, insufficient and bad. For the analysis of the survey results, the multi-criteria analysis is used. By calculating the weighted average per scenario, the acceptance scores can be determined. The higher this score, the less easily the robot is accepted. The lower the acceptance score, the quicker the robot is accepted, because the factors related to acceptance are considered less important. To be able to tell whether the robot is accepted in the setting, the acceptance scores have to be linked to the performance. Since the level of performance is known from the test-case, these scores are combined with the acceptance scores.

For the traffic environment to be roboready, the level of performance has to be sufficient (<= 50) and the robot must be accepted, in all settings. Subsequently, to determine the level of roboreadiness, the combinations of the performance and acceptance scores have to be considered.

In the last stage of the assessment method development, the method is validated. As a demonstration, the method is executed at the traffic environment at the campus of the Erasmus University Rotterdam. All steps were followed, which led to the levels of performance and social acceptance of all settings. This subsequently led to the level of roboreadiness of the traffic environment. This makes that the assessment method is valid, since the purpose of the method has been fulfilled.

Discussion

From the validation a number of things emerges that could improve the assessment method. The main point of improvement is using data from the robot in the test-case instead of obtaining data by means of observations. Implementing the method would take a lot less time. Furthermore, in the determination of the level of roboreadiness, the level of performance and the level of social acceptance have the same weight. Nevertheless, it could be the case that one of them is more important and should have a higher weight than 50%.

The results obtained in the validation of the method can serve as first insights regarding the delivery robot in the traffic environment at the campus of the Erasmus University Rotterdam. Overall, the findings indicate that settings where there is space to pass each other easily, are the most favourable. This combines well with the fact that the predictability of the delivery robot seems important, because with more free space on the road a worse predictability might be less applicable.

With the development of the assessment method, this research contributes to the theory building in the field of delivery robots. The method can be seen as a start to which improvements can be made. Being able to determine the level of roboreadiness of a traffic environment can support in the future roll-out of delivery robots in the public space. However, the research knows some limitations. First of all, the scope of the research is limited. The assessment method is only meant for active modes environments, and no difficult traffic situations are taken into account. Therefore, the method can only be representative for similar traffic environments as the campus of the Erasmus University Rotterdam. Furthermore, the validation of the method was performed in the first pilot with delivery robots in the Netherlands. This makes that (the results of) the survey may not be representative for future projects. People may assess their acceptance differently when delivery robots are more common.

Conclusion & recommendations

With the desk research and the assessment method development, an answer is given to the main research question: “How can the roboreadiness of a traffic environment be determined?”.

With the knowledge acquired from the literature review, a conceptual model was made showing the relations between the elements and listing the influencing factors. In order to assess the factors, to be able to determine the performance and social acceptance in a scenario, a test-case and a survey were constructed. This part of the assessment method leads to the level of roboreadiness of the traffic environment, by analysing the performance and acceptance scores per scenario. Since the validation has shown that the intended objectives have been achieved, it can be concluded that the test-case and survey can be used to determine the roboreadiness of a traffic environment. However, it is desirable to improve the method, to make it more reliable.

Nevertheless, the proposed assessment method is a step in the right direction. Further research could proceed on this, by making improvements to the method. This can make the results more accurate and reliable. Moreover, the proposed assessment method could be executed in the right way, on large scale. Then, the influence of the traffic environment on the level of performance and social acceptance can be determined. If this shows evident relations, conclusions might be drawn on the impact of certain traffic situations on the performance of the robot or the acceptance by people. This is valuable for the implementation strategies regarding delivery robots. Then it can be said which traffic situations are desirable for suitable robots, without realising a pilot.

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1 Introduction

In the world of today, everything has to be better, faster and more sustainable. There is a search for alternative ways of allowing processes to take place without human intervention. More and more processes and actions become autonomous, like the last-mile delivery of packages and groceries. But is society ready for this? This chapter discusses the context of this debate, which leads to a problem definition. Then, the objective of investigating this topic and related research questions are explained, followed by the scientific and societal relevance of this research, to mark the contribution of this study. An outline of the remainder of this thesis ends this chapter.

1.1. Context

The current trend of automation and digitisation has major consequences on the way products are manufactured and distributed. The fourth industrial revolution is unfolding and connects the physical to the digital world. Technologies in this ‘Industry 4.0’ era enable machines and computers to communicate with each other, allowing decision-making processes to take place without human intervention (Stampa, 2020). This results in logistical challenges in the whole supply chain, requiring a transition to what is called ‘Logistics 4.0’. By using smart systems based on new technologies, logistical tasks can be automated which improves efficiency and performance (Jagtap et al., 2020).

Currently, last-mile logistics are the least efficient step within supply chains and could benefit from this fourth industrial revolution (Ranieri et al., 2018). Last-mile logistics cover the last step of the delivery process, transporting freight from the warehouse or distribution centre to the final destination (Olsson et al., 2019). This usually concerns packages to be delivered to the door of the customer’s house. As mentioned by Ranieri et al. (2018), last-mile logistics cover around 28% of the total delivery cost.

Last-mile delivery is facing multiple challenges, requiring technological innovations to keep up with the high demand and the service requirements (Boysen et al., 2020). First of all, due to globalisation and the growth in e-commerce, freight transportation has increased in volume. Another trend that affects last-mile delivery is urbanisation. To handle the demand, delivery vans, scooters and bikes of many different providers are driving around in cities, thereby causing a nuisance. This is not only in terms of congestion, but also in forming obstacles on sidewalks. With the growing attention towards sustainability and new legislation aimed at mitigating climate change, there is a call for environment-friendly alternatives for last-mile delivery (Kiba-Janiak, Marcinkowski, Jagoda, & Skowrońska, 2021).

Furthermore, due to competition, delivery prices are relatively low and delivery speed keeps on increasing. Next-day, or even same-day delivery are becoming the standard. As a consequence, delivery companies have to scale up in a short period of time. This is already leading to a shortage of trained and experienced parcel deliverers (De Buren, 2021). In combination with the fact that the workforce is aging, there is an impending shortage of staff. As a consequence, packages are delayed and customers do not receive their products on time. Alternative delivery concepts that are less dependent on human activity are therefore desirable.

To overcome the above-mentioned challenges, different innovative delivery concepts, such as autonomous vehicles for logistical purposes, are proposed. Automated goods delivery is expected to cover 80% of all business to customer deliveries in the future (Joerss et al., 2016). In some areas in the world, delivery robots are already used in daily life. For example, Starship Technologies operates in several countries in Europe and in the United States, and numbers grow exponentially, as can be seen in Figure 1.1 and Figure 1.2. In the Netherlands however, these robots are not yet allowed due to lack of regulations. With the rapid developments of automated vehicles and the transition to Logistics 4.0, it is plausible that robots will play a role in freight transportation. The question is what this future will be like and how to get there.

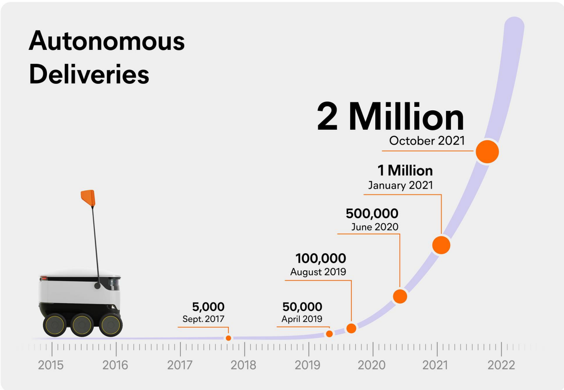


Figure 1.1: Starship's deliveries worldwide (Heinla, 2021).

Figure 1.2: Starship's operating locations (Heinla, 2021).

1.2. Problem definition

Current literature on the topic of delivery robots shows that automation in last-mile logistics could lead to cost and time reduction and can provide a sustainable way of delivering goods (Chen et al., 2021; Figliozzi & Jennings, 2020; Lemardelé et al., 2021). However, there is a need for more research on the integration of delivery robots in the public space (Li, Rombaut, & Vanhaverbeke, 2021). In this research, integration is defined as the performance of the delivery robot within the existing infrastructure. It expresses the level of interaction between the robot and its surroundings. This includes other road users and the traffic environment, consisting of physical aspects of the infrastructure and the traffic conditions. Public space can be understood as a place that is accessible to people, or in other words, property that is open for public use. This includes roads, public squares, pavements, parks, and so on. To be able to manage it, the public space is highly regulated. The way the integration is realised could influence the acceptance by society, mostly the people directly interacting with the delivery robot without consciously choosing to do so (Li et al., 2021; Pani, Mishra, Golias, & Figliozzi, 2020). This group of people can be seen as non-users, having to deal with the robot commuting on the same site.

Next to this knowledge gap on integration of delivery robots in the public space, last-mile delivery concepts also lack theoretical perspective (Boysen et al., 2020; Olsson et al., 2019). Theoretical models can address and simplify complexity, allowing the display of key elements and their relationships. This is essential for an efficient application of the concepts. Before operational decision tasks are to be executed (which can be short-term decisions focusing on the details of operations and delivery routing), these concepts should first prove their competence (Balaman, 2019). Since the delivery robot is a relatively new concept, the research area is growing and not yet mature, which could be the reason for the lack of theory. Studies are limited because there are relatively few cases, so not much data is available on the performance of delivery robots. Studies from countries where delivery robots are being used (USA, UK, Germany, Denmark, Estonia), are not directly applicable to the Netherlands because of infrastructural and cultural differences.

Overall, there is a lack of knowledge on integration of delivery robots in the public space. Next to theoretical models, also data on performance and social acceptance is scarce, since there is not much experience with autonomously driving delivery robots yet.

1.3. Research objective and scope

As mentioned in the problem definition, more research is needed on the integration of delivery robots in the public space. This research aims to propose a methodology that can be applied to determine the 'roboreadiness' of a traffic environment, which expresses whether the environment is ready for delivery robots to drive there. As the robot has to deal with a lot of robot-environment and human-robot interaction, the success of the implementation depends on both: the performance of the robot in the given traffic environment and whether people are prepared to interact with it. The performance and social acceptance are assumed to depend on the traffic environment, since the latter is a given in this research. By studying the factors of both elements at different traffic situations, a possible correlation could be examined. To be able to assess this, a method has to be developed first. This needs to be validated, which is done empirically by executing the method in a pilot with a delivery robot in the Netherlands.

In order to contribute to the theory building in this research area, the goal is to create an assessment method. By doing desk research, the key elements for the integration of delivery robots in the public space are studied. Then, a method is developed which makes it possible to determine the level of roboreadiness of a traffic environment.

The empirical validation concerns a delivery robot at the campus of the Erasmus University Rotterdam (EUR), where groceries from the supermarket SPAR are delivered to customers on campus. The delivery robot is produced by Cartken, and operates at walking pace by calculating the shortest route to its destination. Using cameras and sensors, it automatically avoids obstacles and stops immediately if, for example, someone jumps in front of it. During the empirical research, two routes are driven, which are approximately 200 and 300 metres in length. A map of the campus is presented in Figure 1.3, showing these routes. The starting point is outside, next to the SPAR, and the destinations are next to the entrances of the Library and Hatta Building, also outside. Therefore, interior spaces are not in the scope. The infrastructure in this area consists of a sloping road, bends, pillars, open square and road narrowing. At this campus site, there are pedestrians and cyclists, which makes it an active modes traffic environment. This research can be representative for similar traffic environments.

Figure 1.3: Routes of the delivery robot at EUR campus (blue: SPAR - Library, orange: SPAR - Hatta).

1.4. Research questions

To fulfil the goal of this project, the main research question is stated as follows:

"How can the roboreadiness of a traffic environment be determined?"

To be able to formulate an answer to the main research question, two sub-questions are defined. These are listed below.

1. What are the factors that determine the roboreadiness of a traffic environment?
2. What kind of methods can be used to assess these factors?

After answering the sub-questions, an answer can be formulated to the main research question. By studying robot-environment interaction and human-robot interaction, the important factors influencing the performance of the delivery robot and the social acceptance can be determined. Lessons learned from delivery robots operating in other countries and the examination of the different elements in the Netherlands during the pilot, contribute to the current knowledge gap and lack of data. This study could therefore support realisation of a future roll-out of delivery robots in the Netherlands.

1.5. Relevance

Most scientific literature on delivery robots focuses on the technologies and on the impacts this alternative can have. However, research is lacking on the integration of delivery robots in the public space. Since it is an emerging topic, it is important to develop relevant theories and add knowledge to the theory building in this research area. It is therefore valuable to investigate the interaction of autonomous delivery robots with its traffic environment. Examining the interaction between the robot, public space and human, could lead to new insights. The gained knowledge and acquired data could support the successful application of new autonomous delivery concepts in the public space in the future. Focusing on the integration of logistics with mobility, contributes to the understanding of how autonomous robots would serve future transport demands.

Next to scientific relevance, this research also serves societal interests. Introducing delivery robots as an alternative for current delivery services, could lead to a more efficient and sustainable way of goods delivery. As mentioned before, to encourage an efficient application of delivery concepts in the public space, research is needed on the integration. Studying how the traffic environment affects the performance of delivery robots and how this is related to social acceptance, adds knowledge to the research area and could thereby help in realising future implementation. It is valuable to know how the delivery robot performs at different traffic elements, to be able to make the right decision where to implement robots. If delivery robots partially replace the standard ways of delivery, negative externalities created by delivery vans will be a thing of the past. Issues like congestion, noise pollution and emissions could be reduced. Another problem that can be tackled if delivery robots are successfully implemented, is the shortage of deliverers. Due to the aging in the Netherlands, the transport sector experiences major hindrance. That could lead to high work pressure and delays in delivery. Delivery robots can prevent this social concern from escalating.

1.6. Thesis outline

The report started with the problem definition, objectives and research questions of this thesis. In chapter 2, the methodology is described that is used to answer these questions. The state of the art of delivery robots is discussed in chapter 3, to gain more knowledge on the developments in the field. To delve into the scientific theory, a literature review is performed in chapter 4. The focus here is on performance and acceptance of technology innovation. The reviewed literature leads to a conceptual model, which is used for the set-up of the assessment method described in chapter 5. Subsequently, chapter 6 elaborates on the test-case and the survey, which are the main parts of the assessment method. Both are validated by means of empirical research, from which the findings are described in chapter 7. Then a discussion follows in chapter 8, hereby reflecting on the assessment method and discussing the contribution and limitations of the research. This all leads to the conclusion, stated in chapter 9, which is supported by recommendations for further research and for practice.

2

Methodology

This chapter presents the research approach and the methodology that is followed during the project. First, the research framework is illustrated and explained. Thereafter, the methods that are used to answer the research questions stated in chapter 1, are described.

2.1. Research approach and design

The aim of this research is to develop a method to determine the roboreadiness of a traffic environment, by assessing the performance of the robot and the level of social acceptance. In addition, this research also provides some first insights into the interaction between delivery robot, human and public space. This research assumes that robot behaviour and human behaviour are dependent on the traffic environment. The behaviour of the delivery robot leads to a certain performance, and the behaviour of people leads to a certain level of social acceptance. To be able to study the interaction between the three elements (delivery robot, human, public space), knowledge is required on the impact factors of the public space on the performance of new transport concepts, and on the impact factors of the public space on the acceptance of technology innovations. The research approach that is used to acquire this knowledge and to develop the assessment method, is given in Figure 2.1.

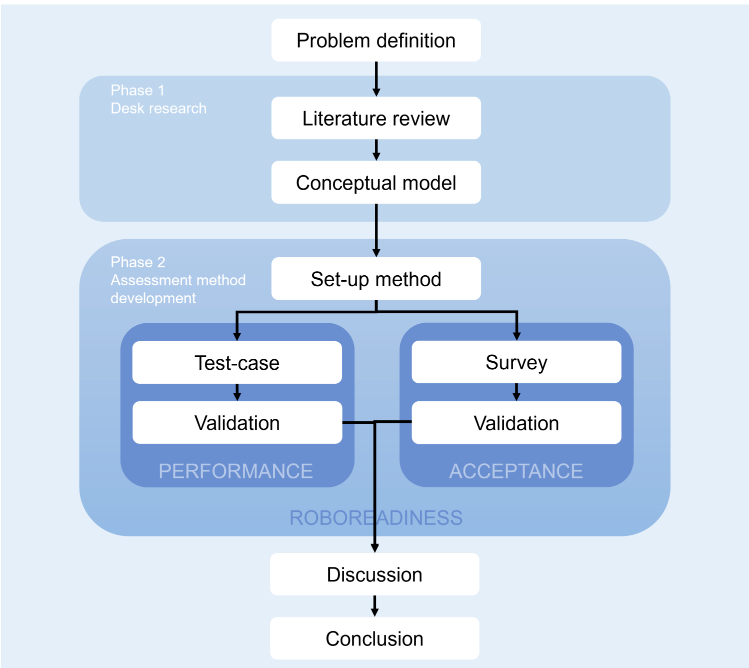


Figure 2.1: Research framework.

The focus in this research is mainly on three elements: the traffic environment, the performance of the robot and the social acceptance. These topics are explored and examined in two phases. The first phase includes the desk research, in which a literature review is performed. This method is used to create a conceptual model, presenting the relations between the elements and showing the influencing factors. This phase provides an answer to sub-question 1.

The second phase is the development of the assessment method, providing an answer to sub-question 2. The conceptual model serves as foundation for the method, with which the level of roboreadiness of a traffic environment can be determined. The roboreadiness is expressed in terms of the performance of the robot and social acceptance. The development of the assessment method is divided into three stages. First, the set-up of the method is defined. Second, the assessment method itself is presented and thirdly this method is validated. The assessment method consists of two parts. To assess the performance of the delivery robot in its traffic environment, a test-case is created. Secondly, to determine the level of social acceptance in relation to the traffic environment, a survey is constructed. Both parts are empirically validated. The empirical research is used to validate the theory-based method in practice, and to get some first insights into the influence of the traffic environment on the performance and social acceptance. Detailed steps within the stages of the development are discussed in the next section. After the validation a discussion follows, to reflect on the proposed method. The findings lead to a conclusion on the main research question how to determine the roboreadiness of a traffic environment.

2.2. Methods

In this section, the methods that are used in this research are described. First, the desk research is discussed, in which a literature study is performed to create a conceptual model. Second, the assessment method development is described, explaining all steps to come to the end product containing two sub-methods, a test-case and a survey.

2.2.1. Desk research

In the first phase of the research, a literature study is performed. Since academic literature on autonomous delivery robots is not extensive, the focus is on existing knowledge on performance of new transport concepts and acceptance of technology innovations. By studying literature on autonomous mobility in public space and robot-environment interaction, factors that play a role in the performance of automated systems are determined. By studying technology acceptance models and human-robot interaction, factors that play a role in determining the social acceptance of innovations in general, become clear. To gain more knowledge on delivery robots, grey literature is studied. This includes articles written for (online) magazines, newspapers and advisory reports. Cases of delivery robots in other countries are studied and compared, to gain insights into the lessons learned and experiences from real-life implementations. It is relevant to explore differences and similarities in these cases, to analyse the performance and acceptance in different traffic environments. From the information acquired in the literature review, a conceptual model is constructed presenting the relation between public space and robot, and between public space and human. The relation between robot and human is not considered in this research due to limited time. The model given in Figure 2.2 forms the basis, showing the relations to be studied. The model is used later on in the development of the assessment method.

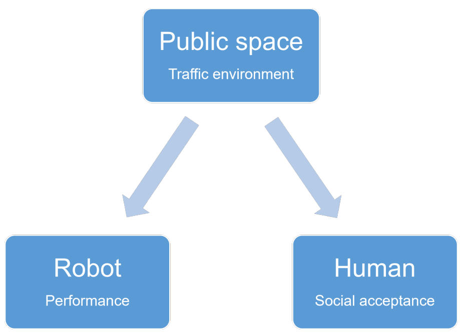


Figure 2.2: The basis of the conceptual model.

2.2.2. Assessment method development

The aim of the assessment method is to be able to determine if a traffic environment is roboready. To verify this, the performance and the social acceptance have to be known, as defined during the desk research. This can be realised by examining the two aspects in the present traffic situations of the traffic environment. The factors that are assessed are based on the conceptual model, created after the literature review.

The assessment method development consists of three stages, namely the set-up, the assessment method and the validation. Each stage contains multiple steps. An overview of the process is presented in Figure 2.3, followed by an explanation of the stages and steps. The sequence of the actions is based on web articles by McMullin (2021) and *Product Performance Testing* (2021).

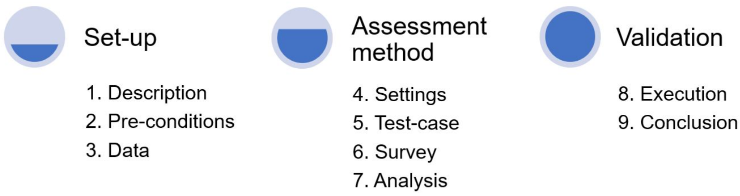


Figure 2.3: Stages and related steps in the assessment method development.

Set-up

The first stage in the development of the assessment method is the set-up. The context of the research and the requirements for executing the method are described here. This applies to the test-case as well as the survey, since both are executed in same traffic environment. This stage contains the following steps:

- Step 1: Description
  At the start of the set-up, the goal behind the assessment method should be made clear and a description of the experiment has to be made. This step should tell what feature is to be examined in what context and why.

- Step 2: Assumptions and pre-conditions
  The second step is stating the assumptions and pre-conditions. The method can be executed if the research falls within the scope and if all conditions are met.

- Step 3: Data
  The factors to be assessed have to be defined before execution of the method. In this step, the indicators should be described and explained.

Assessment method

Now that the context for the research is clear, the actual assessment method can be developed. To determine the roboreadiness of the traffic environment, two main aspects are to be examined, namely the performance and the social acceptance. Since these aspects require different data gathering techniques, the assessment method contains two different sub-methods. The steps to carry out in this stage are as follows:

- Step 4: Settings
  The first step in the assessment method, is to divide the traffic environment into traffic situations. Settings have to be created, in which the performance and social acceptance are to be assessed.

- Step 5: Test-case
  To assess the performance factors in the settings, a test-case is to be developed. A test-case can be used for examining functionality in a certain context and thereby verify expected results (Oztemel et al., 2009). Hence, in this way the impact of the traffic environment on the performance of the robot can be examined. The actions that have to be performed to obtain results are outlined in this step.

- Step 6: Survey
  To assess the social acceptance factors in the settings, a survey is to be created. By questioning people who have interacted with the delivery robot in the traffic environment, values can be attached to the factors. By showing different settings, the impact of the traffic environment on the social acceptance of the robot can be examined. A template of the survey is created in this step and the way to obtain results is explained.

- Step 7: Analysis
  The results that have been obtained by performing the two sub-methods are to be analysed. A statistical analysis is to be carried out on the data, whereafter these are interpreted. The last step of the analysis is to translate the results to the levels of performance and social acceptance. Therefore, criteria need to be set up. These values are verified by an expert from the company this research is performed for. This analysis results in the assessment of the roboreadiness of the traffic environment.

Validation
To check the accuracy and demonstrate whether the assessment method is suitable for application, the last step is to validate the method. Adjustments to the method may be needed to increase the reliability. The validation is done by following the steps from the assessment method stage and acquire real-life results. Therefore, the last steps are as follows:

- Step 8: Execution
  The four steps of the assessment method are carried out on a small scale, to check the validity of the method. The execution has to show whether the intended purpose of the method is achieved.

- Step 9: Conclusion
  To end the assessment method development, the conclusion of the validation is described. Due to time constraints, potential improvements are not incorporated into the method but remain only suggestions. Therefore, the validation is not used to adjust the method till it is optimised, but shows whether the method is a good first start in the research area of delivery robots.

3

Delivery robots - state of the art

To introduce the main topic of the research and the object used in the assessment method, this chapter discusses the state of the art of autonomous delivery robots. First, the concept of the delivery robot is described. Here, the definition, benefits and risks are clarified. Thereafter, the legal and regulatory aspects are mentioned, since this plays an essential part in the implementation and success of the delivery robot. In the third section, three delivery robots of different companies are presented, to get an idea of the role and usage of delivery robots around the world and to specify the characteristics of the robot used in the empirical part of this research. For the full picture, other concepts of autonomous delivery are presented in section four. At last, the takeaways of this chapter are outlined.

3.1. Concept of a delivery robot

In order to manage the enormous increase in business to consumer (B2C) e-commerce and meet the sustainability goals of the future, new last-mile logistics strategies are needed. Lately, there is much attention for unmanned self-driving vehicles to fulfil logistical purposes, also known as autonomous delivery robots. The expectation is that automated goods delivery will account for 80% of all B2C deliveries in the future (Joerss et al., 2016). Multiple companies are producing and testing delivery robots already.

A delivery robot is an automated vehicle, able to deliver goods at a designated place and thereby covering the last-mile of the delivery process (Starship, 2021). Small delivery robots are designed to commute on the sidewalk, thereby behaving like a pedestrian. By using the latest technologies and lots of cameras and sensors, the delivery robot can navigate around obstacles and people, driving at pedestrian speed. Because of this relatively low speed and light weight, the robot is able to stop immediately when necessary. While the robots are running autonomously, a remote human operator can always take over control if intervention is needed (Bellan, 2021). The design and characteristics of a common sidewalk delivery robot can be seen in Figure 3.1.

Figure 3.1: Specifications of Starship's delivery robot (Cooper, 2021).

Starship Technologies is one of the companies that launched a delivery robot, and they already reached three million autonomous deliveries. Results show that it is an effective alternative for last-mile delivery (Heinla, 2021). This is in line with the literature on this topic. Multiple researchers state that delivery robots can lead to time-savings, energy and emissions reductions and cost minimisation (Chen et al., 2021; Figliozzi & Jennings, 2020). However, since it is a new concept, relatively speaking not many cases exist. Therefore, the prove that it is a good alternative to current delivery services, is limited.

Next to the benefits delivery robots could bring, there are also downsides and challenges to overcome. The main reason that in the Netherlands delivery robots are not used yet in daily life, is because the regulations do not allow it. Van Petegem, van Nes, Boele, and Eenink (2018) state in an advisory report that experimenting with innovative transport modes on public roads will always involve a certain degree of risk. Specific regulations for autonomous delivery robots in the public space are lacking and the legal infrastructure for these innovative solutions is incomplete or non-existing.

Autonomous robots are already being used in other sectors for some time, for example inside warehouses and factories. Here the robots lead to significant reductions in time and cost (Jaller, 2021). Driven by these results, developers have started to design robots for other sectors, like last-mile logistics where time and cost could be improved. However, automation in this sector brings challenges, considering the dynamics of the surroundings. This can include changing infrastructure and the behaviour of other road users. How the integration of delivery robots in the public space in the Netherlands will work out in terms of social acceptance and the fit in environment is still an open question.

From the current literature, it can be concluded that last-mile logistics are an inefficient step in the supply chain, because of the low degree of automation. New technologies should provide solutions for the many challenges in this field. The delivery robot is a promising innovation that could lead to cost and time reduction and provides a sustainable way of transportation. The technologies have proved themselves and robots can function as they should. However, the legislation, infrastructure and social acceptance might not be ready yet. The next step in research is therefore to study if delivery robots can successfully be implemented, focusing on the performance and the social acceptance in relation to the traffic environment.

3.2. Legal and regulatory aspects

All over the world, companies are developing autonomously driving delivery robots. The technologies advance rapidly, but the legislation to support this innovation on last-mile delivery, is incomplete or even lacking in many countries in the world. The increasing appearance of delivery robots in public space, reveals the shortcomings in the laws and regulations and urges the need for standards (Hoffmann & Prause, 2018). Legal issues have to be addressed before a large scale roll-out of delivery robots becomes possible.

Concerns exist on multiple aspects, which can be categorised as follows (LMAD, 2021):

- Safety of other road users
- Liability issues when an accident happens
- Privacy and data protection

In the European Union, no specific regulations exist for autonomous robots for logistical purposes in public space. This means implementation possibilities can vary from country to country. In the public space, delivery robots have to share the roads with other road users, vehicles and devices. In such a dynamic traffic environment, it can be hard to get the necessary legislative permissions. Authorities on local and national level are cautious to give admission in large cities and city centres. For this reason, current operating delivery robots are primarily deployed in urban areas with a low traffic density, or in closed areas like campuses, where pedestrians and obstacles are easy to avoid (LMAD, 2021). Furthermore, there is always someone watching remotely, giving instructions to the robot when asked and always able to take control if needed.

3.3. International cases

Experiences from other countries where delivery robots are already used, can be useful for this research on suitable traffic environments. Therefore, existing cases are studied. It is interesting to explore differences and similarities in these cases, to analyse the performance in different surroundings. Three different small delivery robots, used for last-mile delivery, are presented in Figure 3.2. First of all, the delivery robot of Starship technology is chosen. This company was the world's first in commercial, autonomous, ground-based package delivery, and has made the most deliveries worldwide (Dormehl, 2019). Second, the delivery robot of Cartken is described, since this robot is used in the validation of the assessment method. It is a similar type of delivery robot as Starship's, but used less. Lastly, the delivery robot of Delivers.ai is discussed. This robot has different characteristics than the previous two, which makes it interesting to compare. The three different delivery robots are described separately in the coming subsections.

(a) Starship Technologies (Starship, 2021).

(b) Cartken (*Cartken*, 2022).

(c) Delivers.ai (*Delivers.ai*, 2022).

Figure 3.2: Three different delivery robots.

3.3.1. Starship Technologies

The delivery robot of Starship Technologies can be seen in Figure 3.2a. The company was founded in 2014 in Tallinn, Estonia, and started its first pilot in 2016. Today, the company already completed over three million autonomous deliveries (Lunden, 2022). The robots deliver parcels, food and groceries, directly from stores to the customer, on a local level (Starship, 2022). Starship mainly operates at university campuses, although robots are placed in suburbs and town centres as well (Ingham, 2020). Currently, the robots are mostly used in the US and UK, but also in Estonia, Germany and Denmark. To name some characteristics of the delivery robot: it has six wheels, drives on sidewalks with a speed of about 6 kilometres per hour, and the container in the robot has the size of a shopping basket.

3.3.2. Cartken

The delivery robot produced by Cartken, is shown in Figure 3.2b. The company was founded in 2019, and is based in the US. It had its first large roll-out of autonomous robots in Miami, in 2019. It concerns small self-driving delivery robots, commuting on sidewalks, delivering dinner orders downtown. The robots are pre-positioned in designated hubs, and are dispatched with orders for delivery as they are prepared. The robot has a similar size and content as the robot from Starship, drives on six wheels, and has a radius of 4 to 6 kilometres (Bellan, 2021).

3.3.3. Delivers.ai

Delivers.ai was founded in 2020 in Istanbul, Turkey, and has developed delivery robots to autonomously deliver parcels, food and groceries from shops to the customer's doorstep (*Delivers.ai*, 2022). The robot is displayed in Figure 3.2c. This company realises the first autonomous robotic delivery service pilot in city centres in Spain (EIT Urban mobility, 2022). The robot commutes on sidewalks of streets within a certain area, with pedestrian speed. The order is picked up by the robot at a supermarket, and delivers food and groceries at the destination (Innovation Origins, 2022). The difference with the previous two delivery robots, is that the robot of Delivers.ai has more volume inside, it has the size of a pram. Besides, this robot has four wheels instead of six.

3.4. Other autonomous delivery concepts

Autonomous delivery concepts have been an emerging trend for several years. Self-driving delivery vehicles know various types and sizes. Besides the delivery robot, the best known concepts that deliver goods autonomously are vans, drones and robot dogs. Images of these concepts can be found in Figure 3.3. The main advantages of autonomous delivery are that the vehicles are electric and unmanned, which eliminates the need for staff. However, an accompanying disadvantage is that with this new concept, laws and regulations are scarce or nonexistent in some countries. An ongoing question is whether autonomous vehicles can safely control unusual and unpredictable situations (Behnke, 2019). The characteristics of the different concepts are discussed in this section.

(a) Van by Nuro (Nuro, 2022). (b) Drone by Flytrex (Taylor, 2021). (c) Dog by ANYbotics (Marchese, 2019).

Figure 3.3: Three different delivery concepts.

3.4.1. Delivery van

The delivery van can be seen as a larger type of the sidewalk delivery robot. As can be seen in Figure 3.3a, it is a small vehicle on wheels, about half the width of a normal car. Since it has the size of a small car, this type of autonomous vehicle drives on the street. Just like the delivery robot, the van needs to deal with diverse traffic situations. Another difference is that in a delivery van, multiple orders can be delivered in one go. These vans bring goods or groceries from a local store to the customer (Etherington, 2018).

3.4.2. Drone delivery

The delivery drone is an unmanned aerial vehicle that can be used to transport packages, food or other goods. In Figure 3.3b, the drone by Flytrex can be seen. In 2017, this company launched the world's first autonomous drone delivery in Iceland. The advantages of using a drone instead of a delivery robot are that it avoids traditional traffic and (therefore) the speed it can have is higher. This also means shorter routes can be taken which can save a lot of time (Yoo & Chankov, 2018). Moreover, drop-off locations know more flexibility. A drone can deliver a package is someone's yard or on a balcony in a flat. However, challenges exist regarding navigable airspace, operation span and weight of the drones. This may be the reason why drones are less used and less visible in the news than sidewalk delivery robots.

3.4.3. Robot dog

Another similar concept as the delivery robot, is the robot dog. The flexibility is a benefit that stands out. The four-legged robot, displayed in Figure 3.3c, can transport a package right up to the customer's door. Robot dogs can easily navigate through human environments, which is the main advantage relative to sidewalk delivery robots. They are able to walk on uneven ground and ring the doorbell of the customer's house with one of the limbs. The introduction of robot dogs in the delivery of goods is far behind delivery robots. They might not be reliable enough yet to complete this task (Vincent, 2019).

3.5. Takeaways

This chapter contains background information on delivery robots. The benefits and risks are explained and the relevance of the innovation is stated, which underpins the importance of this research. The general information gives insight into the characteristics of delivery robots, so readers better understand the context of the remainder of this thesis.

One of the main takeaways of this chapter is that delivery robots could have a great potential to support or take over current delivery services in these times of urbanisation and immense increases in e-commerce, but that there are also challenges to overcome. Especially legislation is a crucial aspect. As the delivery robot is a relatively new concept, it lacks regulations. Furthermore, the crowding of cities makes that streets become busier. Less space remains, which raises the question where delivery robot should drive.

As evidenced by the introduction of delivery robots in various countries around the world, popular locations are university campuses. This is because these areas usually have a low traffic density and less complex traffic situations. In this research the influence of the traffic environment on the performance of the delivery robot and on the social acceptance is studied, which may contribute to the introduction of delivery robots in other public spaces. Comparing the delivery robot to other autonomous delivery concepts tells that the sidewalk delivery robot is the best known and most used concept at this moment. It seems to be the easiest and safest way to deliver goods autonomously among these concepts.

4

Towards a conceptual model of influencing factors of roboreadiness

In order to successfully implement delivery robots in public space, it is important that the robot interacts with the environment. In the environment the robot encounters multiple aspects, such as the physical infrastructure, traffic conditions and people. Since the physical characteristics of the infrastructure are often a given, the delivery robot has to adapt to the present circumstances. It is essential that the traffic environment and the people are ready to deal with the delivery robot when it is implemented (Oztemel et al., 2009). To make sure that the robot can be successfully implemented in a certain area, the relation between the traffic environment and the performance of the robot, as well as the relation between the traffic environment and the social acceptance need to be known.

Academic literature on last-mile autonomous delivery robots is scarce, since it is a relatively new concept. Therefore, scientific papers on technology innovation with regard to mobility in general are analysed in the desk research. In the first section, articles about the performance of new transport concepts are discussed. This results in a list of factors that determine the performance of a delivery robot in the traffic environment. In the second section, the social acceptance of technology innovation is discussed, by comparing several models and studying human-robot interaction. This part also ends with a list of influencing factors. The findings are translated into a conceptual model, presented in the third section. To summarise the findings, a conclusion is written at the end of this chapter.

4.1. Performance of new transport concepts

The performance of a new technology is an essential indicator for the level of success (Tian, Wu, Boriboonsomsin, & Barth, 2018). The performance states how the robot performs in the given traffic environment. In this section, factors that play a role in the performance of transport concepts are discussed. Spatial requirements and traffic conditions applicable to automated systems in the public space are studied, as well as robot-environment interaction. To gain insight into examining the performance of new transport strategies, other initiatives concerning mobility innovations are reviewed. This creates a better understanding of the influence of the traffic environment on new transport concepts.

4.1.1. Autonomous mobility in the public space

The challenges of today arise in adapting cities to its current needs (Paiva, Ahad, Tripathi, Feroz, & Casalino, 2021). Ideally, transport innovations should be functional within the existing environment. On the other hand, when areas change or if they are newly built, the environment can be suitably adapted to the innovation. When integrating new transport concepts in the traffic environment, it is important to study the interaction between the innovation and its surroundings before realising the implementation. Tomitsch and Hoggenmueller (2021) state that it is a challenge to design or implement automated systems in public spaces, because it can be dependent on the physical context, the people involved and their norms. Fisher (n.d.) introduced a set of principles that can provide guidance for designing automated applications in urban areas. These principles include the integrity and quality of the urban realm, enclosure and continuity, ease of movement, accessibility, diversity, legibility and adaptability. The flow of people must not be adversely affected (Tomitsch & Hoggenmueller, 2021). With the implementation of delivery robots in public spaces, it is essential that these principles are not violated. When examining the performance, these aspects are thus important to take into account. Performance factors in case of the delivery robot that are covered by these aspects are continuity, deviation (ease of movement) and pace (adaptability).

4.1.2. Robot-environment interaction

Not much is examined yet about the interaction between a delivery robot and its environment. However, the performance in public spaces of other types of robots is investigated, for example by Oztemel et al. (2009). They defined a set of criteria to measure and quantify the performance of swarm robots. The criteria belong to five aspects that cover all important indicators for measuring performance. These aspects are defined as feasibility, manageability, usefulness, acceptability and necessity. The first two aspects can be applied to the context of delivery robots within the traffic environment. Feasibility implies that the costs, risks and technology the robot brings, are feasible. Speaking about the performance of the delivery robot, this means the robot must operate safely. The other aspect, manageability, entails functions of the robot that can easily be performed without violating operational rules. For delivery robots this can be interpreted as not violating traffic rules, which gives the factor compliance.

4.1.3. Factors determining performance

This research focuses on the factors that determine the performance of the delivery robot in relation to its traffic environment. Therefore, the influencing factors are limited to the part when the robot is driving, it does not take into account the performance related to the delivery service (for example the pick-up/drop-off). In Table 4.1, an overview is presented listing the factors that determine this performance. Every factor is followed by an explanation.

Table 4.1: Factors determining the performance of a delivery robot.

Factor	Explanation
Pace	The speed of the robot
Continuity	Continuous driving
Deviation	Not staying on track
Safety	The robot should not run into obstacles/people
Compliance	Does the robot follow the traffic rules?

4.2. Social acceptance of technology innovation

Acceptance is an important aspect for technological innovations implemented in public space. An innovation can succeed or fail based on the social acceptance. Even if the innovation can improve efficiency and is more sustainable than the alternative, it will only be a success if people interact with and accept it (Devine-Wright, 2007). In order to be accepted, the innovation has to meet basic usability requirements and be recognised as useful (Dillon, 2001). Acceptance is a broad term and does not have one single definition. It can also be different for users and non-users of the innovation. This research focuses on the innovation within the traffic environment. Therefore, the social acceptance is studied, which expresses the acceptance by people who interact with the innovation on the streets. This includes non-users, like pedestrians or other road users who do not necessarily choose to use or interact with the delivery robot, but have to coexist with it and are thus involuntarily exposed to the innovation.

Technology acceptance models show the factors that determine the acceptance of technologies. Numerous models exist, specified for a certain technology or an expanded version compared to previous models. Models can be seen as a representation made to explain a theory. Theories can be considered as a set of principles, intended to explain something. The aim of this section is to define relevant factors in the case of the delivery robot. Therefore, acceptance models regarding technology innovation are explored first, followed by a discussion about human-machine interaction.

4.2.1. Technology acceptance models

Most technology acceptance models focus on the acceptance of the user of the technology. The original and widely used Technology Acceptance Model (TAM) of Davis (1989) presents two factors that, according to him, determine the acceptance; perceived ease of use and perceived usefulness. These factors have a positive correlation with the intention to use the technology. This is thus a usage-related acceptance model. The factors are influenced by aspects like subjective norms, relevance, and attitude toward technology. Many researchers have built upon TAM, in different areas of research. Another well known acceptance model is the Unified Theory of Acceptance and Use of Technology (UTAUT), by Venkatesh, Morris, Davis, and Davis (2003). Here, the two factors from TAM are translated into performance expectancy and effort expectancy. In addition, social influence is added in this model. These two models, TAM and UTAUT, are general and can be applied to all sorts of technologies.

More specific models, to narrow down to the context of automated systems, are the Automation Acceptance Model (AAM) and the Car Technology Acceptance Model (CTAM). These are created as an expansion of the original models, and include factors like trust, safety, and anxiety (Ghazizadeh, Lee, & Boyle, 2012; Osswald, Wurhofer, Trösterer, Beck, & Tscheligi, 2012). In robotics research, acceptance models exist as well and focus on aspects like appearance and social ability of the robot. One example is the so-called Autonomous Delivery Vehicle Acceptance Model (ADV-AM), which includes the constructs that predict the behavioural intention to use delivery robots. This model is created by Kapser and Abdelrahman (2020), who investigated the acceptance by users of delivery robots in Germany, adapting an extended UTAUT model to the context of last-mile delivery robots.

All models mentioned so far, predict actual system usage and thereby focus on acceptance by the user of the technology. However, in case of the delivery robot, non-users are also important to take into account. Non-users are people being nearby the delivery robot, who involuntarily have to deal with the robot commuting on the same site. They do not necessarily have the behavioural intention to use the technology. Therefore, aforementioned models are not directly applicable to delivery robots. However, acceptance can still play an role, to assure a smooth coexistence on the sidewalks. To keep the overview of the different acceptance models, Table 4.2 shows the models and their belonging factors.

Table 4.2: Acceptance models and associated factors.

Model	Source	Factors
TAM	Davis (1989)	perceived ease of use & perceived usefulness
UTAUT	Venkatesh et al. (2003)	performance expectancy & effort expectancy & social influence
AAM	Ghazizadeh et al. (2012)	compatibility & trust & perceived ease of use & perceived usefulness
CTAM	Osswald et al. (2012)	perceived safety & anxiety & performance expectancy & effort expectancy & social & influence & facilitating conditions & self efficacy & attitude towards using technology
ADV-AM	Kapser and Abdelrahman (2020)	perceived risk & price sensitivity & performance expectancy & effort expectancy & social influence & facilitating conditions & hedonic motivation
EA	Abrams, Dautzenberg, Jakobowsky, Ladwig, and Rosenthal-Von Der Pütten (2021)	competence & discomfort & interest & trust & enjoyment & threat & general perceived usefulness for society & subjective social norms

Abrams et al. (2021) explain why the current technology acceptance models are not suitable to apply to delivery robots. Usage-related technology acceptance includes intentional and social interaction, appearance and form, usage, and autonomy. These aspects are not necessarily relevant for non-users, they explain. For that reason, Abrams et al. (2021) introduced a new concept and came up with the term Existence Acceptance (EA). Hereby, the focus is on the acceptance of a technology by non-users.

This means passive approval of the presence of the delivery robot. Several factors should be taken into account to determine the existence acceptance. These are defined as the level of competence, interest, discomfort, enjoyment and the general perceived usefulness for society and subjective social norms.

4.2.2. Human-robot interaction

Not many studies exist about the interaction between delivery robots and people. However, research about other automated systems provides some insights. Fraedrich and Lenz (2016) write about acceptance of autonomous driving, whereby results of other studies are analysed and used as input for their own investigation on the view of road users on the technology. The authors state that acceptance is case-specific and indicators are not directly interchangeable. In the research process, it is important to reflect whether factors used in other acceptance studies can be used or that factors have to be excluded. In their article, they present a two-level category system, whereby within a certain context, object-related as well as subject-related aspects play a role. To apply this on the empirical part of this research, the context is the traffic environment at the campus of the Erasmus University Rotterdam, the object is the delivery robot and the subject is the people. The research of this thesis is limited to the acceptance related to the operational part of the delivery robot. Therefore factors like privacy or design are not taken into account. This makes that only the aspects ‘perceived features of the technology’, and ‘evaluative attitudes and expectations’ from the two-level category system are applicable to this case. Factors that belong to these aspects are comfort and convenience, and interest respectively. Comfort and interest correspond with the theory of existence acceptance of Abrams et al. (2021).

Another example of human-machine interaction with regard to autonomous driving, is about the acceptance of semi-automated truck platooning. In a study by Castritius et al. (2020), people from Germany and California were asked to fill in an online questionnaire about their attitudes towards the technology and behavioural intention to cooperate with heavy truck platoons. Constructs that can be translated to delivery robots in the public space are expected usefulness of the concept, expected ease of sharing the road, and specifications of the vehicle. Associated factors for delivery robots are general perceived usefulness, predictability and dimensions of the robot respectively.

4.2.3. Factors determining social acceptance

From the literature about technology acceptance models and human-machine interaction, various factors can be extracted that influence the acceptance of an innovation. This research focuses on the impact of the traffic environment on the social acceptance. Therefore, only factors that can vary per environment are considered, and not the factors that determine the acceptance in general. This leads to the list of factors presented in Table 4.3. Every factor is followed by an explanation.

Table 4.3: Factors determining the social acceptance of a delivery robot.

Factor	Explanation
Predictability	Does the robot react according to expectation?
Competence	Is the robot reliable and capable in its functioning?
Comfort	Is the robot not a nuisance?
Dimensions	The space it takes on the path

4.3. Conceptual model

In the previous sections, the factors belonging to the performance and social acceptance are explained. The aim was to study the influences the traffic environment has on the performance and on the social acceptance. Therefore, a conceptual model is created, showing the existing connections between public space, robot and human. The model is illustrated in Figure 4.1. The elements in the conceptual model are the basis of the development of the assessment method. The factors are the core aspects that are used in the sub-methods. The connections in the conceptual model are explained below.

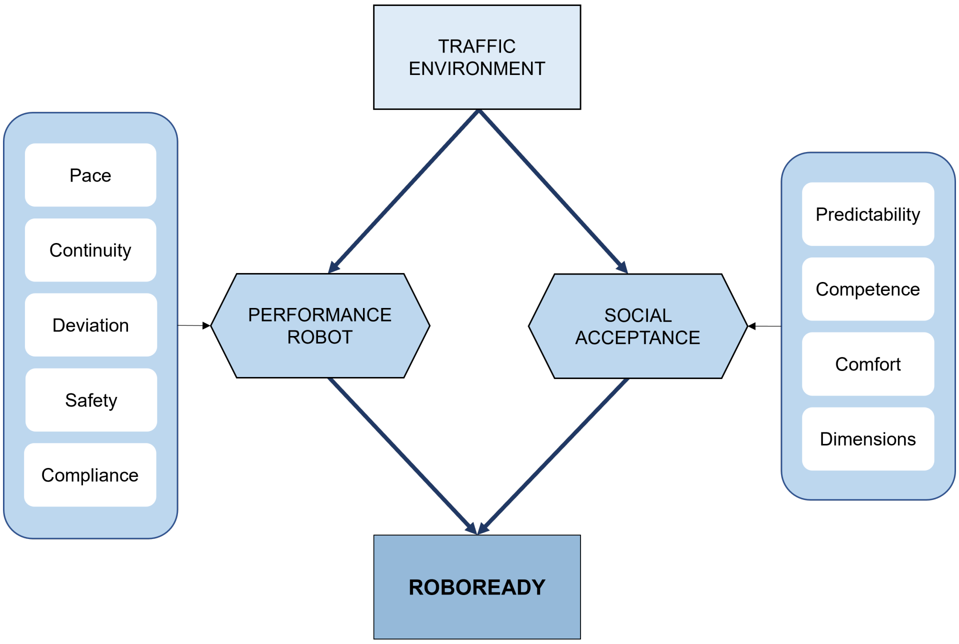


Figure 4.1: Conceptual model of the factors influencing the roboreadiness.

The traffic environment is given in this research and has an influence on both the performance of the robot as on the social acceptance. In the model, the factors that determine the performance and the social acceptance are listed next to the elements and connected with an arrow. The value of these factors determine the level of performance and the level of social acceptance. Consequently, this determines the state and level of 'roboreadiness'. This can be interpreted as the society being ready for the delivery robot to be part of the street scene. When the factors have an acceptable value and therefore ensure a sufficient level of the elements, the delivery robot can be successfully integrated in the public space.

4.4. Conclusion

In the literature review performed in this chapter, the important factors determining the performance and acceptance of technology innovations were studied. It turns out to be challenging to implement automated systems in public space because of the dynamic environment. This makes it even more relevant to study and explore the robot-environment interaction. Factors that seem to be important when investigating the performance of autonomous sidewalk delivery robots, in the spatial context, are 'pace', 'continuity', 'deviation', 'safety' and 'compliance'.

Furthermore, the review reveals that acceptance is often about the intention to use an innovation. However, in case of delivery robots people have to coexist with it even though they do not choose to do so. Therefore, factors from existing acceptance models do not necessarily apply in the case of the delivery robot. Nevertheless, a recent study proposed the term existence acceptance, from which influencing factors can be included in this research. The factors influencing social acceptance in a spatial context, are 'predictability', 'competence', 'comfort' and 'dimensions'.

The findings from the desk research were transposed into a conceptual model (Figure 4.1), showing the relation between the elements and the influencing factors. The model serves as foundation in the development of the assessment method. Hereby, this chapter has contributed to answering the research question, by providing an answer to the first sub-question: *"What are the factors that determine the roboreadiness of a traffic environment?"*

The next step is to determine how the performance and social acceptance can be assessed, in order to tell if the traffic environment is roboready. However, no method exists yet to examine these elements for delivery robots. In the next chapters the assessment method is developed, which makes it possible to assess the influence of the traffic environment on the performance and the social acceptance.

5

Set-up method

The development of the assessment method starts with the set-up. The goal of the method is to determine the level of roboreadiness of a traffic environment. The method can be relevant for companies wanting to implement delivery robots in the public space and realise a pilot to determine if the environment is suitable. This can be verified by assessing the performance and social acceptance in different traffic scenarios. Therefore, it is important to define the elements and the context for which the assessment method can be applied. The coming three sections discuss the description, the assumptions & pre-conditions, and the data that have to be obtained, respectively. The chapter ends with a synopsis.

5.1. Description

The first step of the assessment method development includes the description. To generate output and be able to determine the level of roboreadiness, the context in which the experiment takes place has to be clear. The context includes an autonomous sidewalk delivery robot in the traffic environment, which consists of two aspects: the physical infrastructure and the traffic conditions.

Infrastructure One of the aspects of the traffic environment is the physical infrastructure. This is expressed in factors, which are a given for the environment. It does not change except if road maintenance is performed. The traffic environment covers several traffic situations. One traffic situation can consist of a combination of multiple factors.

Traffic conditions The other aspect that is part of the traffic environment are the traffic conditions. The factors that are included reflect the characteristics of the environment around the delivery robot. Some of these are a given within the traffic environment, others can change at any time.

Table 5.1 gives an overview of the factors of the traffic environment considered for this research, divided into the two aspects. The factors are chosen based on the pilot taking place at the campus of the Erasmus University Rotterdam, since this traffic environment is used for validation of the method. It includes the most common factors of traffic environments. The factors are provided with an explanation.

Table 5.1: Factors of the traffic environment.

Factor	Explanation
Infrastructure	
Width	Wide or narrow (>= or < 2 metres alongside the robot)
Alignment	Curves or straight path
Crossings	Paths from other directions: yes/no
Elevations	Flat or change in elevation
Traffic conditions	
Other road users	Pedestrians and/or cyclists
Intensity	Amount of traffic: # of people in $r = 5m$ around the robot
Density	Amount of free space: free m^2 in $r = 5m$ around the robot

Table 5.1: Factors of the traffic environment.

Factor	Explanation
Visibility	Field of vision: % of the view that the robot can see
Speed	Speed of the other traffic participants in km/h

5.2. Assumptions and pre-conditions

The next step is to state the assumptions and pre-conditions. The assessment method can be used if the goal of the research is in the scope of the description, and if all the conditions are met. The assumptions and pre-conditions are listed below.

Assumptions

- The traffic environment is a given and does not change.
- There are no extreme weather conditions at the time of execution.
- The delivery robot functions properly under normal circumstances.

Pre-conditions

- The delivery robot has to be driving autonomously, and not manually operated.
- The traffic environment has to be an active modes traffic environment.
- There are no other factors present in the traffic environment than the ones listed in Table 5.1. Combinations of the factors can be included.
- The traffic environment must contain the traffic conditions listed in Table 5.1, and no other characteristics than that.

5.3. Data

The last step before the assessment method can be created, is to specify the data. The variables to be assessed and their values are explained in the following subsections. The subsections are separated into two parts: performance and social acceptance, respectively.

5.3.1. Performance

To assess the performance, indicators of the factors have to be defined. The factors are monitored during the execution of the method, and evaluated based on the value of the indicator. The indicators belonging to the factors are presented in Table 5.2 and elaborated below.

Table 5.2: Indicators of the performance factors.

Factor	Indicator
Pace	Number of times speed of robot differs with other traffic participants
Continuity	Number of unnecessary stops
Deviation	Number of times robot unnecessarily deviates from the path
Safety	Number of collisions
Compliance	Number of violated traffic rules

Pace The pace of the delivery robot is an important factor in determining the level of performance. It is not the case that driving faster is always better. The robot should adapt to its environment and therefore have approximately the same speed as the other road users. To value pace, the number of times the speed of the robot is different from the speed of surrounded traffic participants has to be counted.

Continuity With continuity, the ease of movement is expressed. The delivery robot should drive smoothly, if the conditions allow. To value continuity, in order to translate it to the performance, the number of unnecessary stops has to be counted.

Deviation The robot calculates the shortest route to its destination. When obstacles are on that way, the robot deviates from this path. Besides the case of avoiding obstacles, the robot should drive a straight line. In order to determine the level of performance, the number of times the robot deviates from its path when it is not needed, has to be counted.

Safety Safety is expressed as not colliding with people or obstacles. To value the factor safety, the number of collisions has to be counted.

Compliance The delivery robot should behave like a pedestrian, when commuting on the sidewalks. Therefore, it has to stick to the norms and rules that apply. Following the traffic rules is required to have a sufficient level of performance. Therefore, the times the robot does not comply with the rules have to be counted.

If the indicator has a positive value, this is called an incident. The value of the indicator is negatively correlated to the performance. For example, the more unnecessary stops the robot makes, the worse the performance. The indicators of the factors of the performance can be assessed by means of a test-case. Test-cases are used to test a product in the specific context (McMullin, 2021). It captures the set of interactions between the product and the context (Kao, 2021). This makes it possible to examine the performance of the delivery robot in the traffic environment. By executing the test-case, factors can be assessed and data obtained which can be used to determine the performance of the robot in the desired traffic environment.

5.3.2. Social acceptance

To examine the relation between the traffic environment and the social acceptance, indicators belonging to the social acceptance factors have to be defined. The assessment of the factors are by definition subjective, this means that people can interpret the factor according to their own standards. Under the exact same circumstances, people can experience the behaviour of the robot differently. Table 5.3 presents the indicators belonging to the factors, of which an elaboration is given below.

Table 5.3: Indicators of the social acceptance factors.

Factor	Indicator
Predictability	Difference in expected and actual behaviour of the robot
Competence	Functioning of the robot
Comfort	Non-annoyance caused by the robot
Dimensions	Size of the robot

Predictability The predictability is defined as the difference in expected behaviour and actual behaviour. To be able to assess this, the question is how important it is to know which path the robot follows. To explore if the level of importance of predictability is dependent on the traffic environment, this factor has to be scored on importance in different traffic scenarios.

Competence For people to accept the robot, it might be essential that the robot operates properly. This competence is expressed in terms of reliability and capability. The level of acceptance can be dependent on the characteristics of the traffic environment. To examine the potential impact of this factor, the importance of the functioning of the robot has to be scored in different traffic scenarios.

Comfort Part of the acceptance is determined by the factor comfort. It is important that the people do not get annoyed by finding a robot on their path. The robot should not cause a nuisance. To value the impact of the traffic environment on the level of comfort, the degree of non-annoyance has to be determined in different traffic scenarios. This is assessed by asking people to score the factor comfort on importance.

Dimensions Delivery robots exist in different sizes. The bigger the delivery robot, the more space it takes on the sidewalk. The size of the robot can thereby influence the acceptance of bystanders. The desirable size can differ per traffic environment. To investigate this potential impact, people who have had experience with the delivery robot on their path, are asked how they would rate the importance of the dimensions of the robot.

By questioning people who are walking in the same traffic environment as the delivery robot, values can be attached to the indicators determining the social acceptance. For this scoring a Likert scale is used, since it is a well-known and reliable way of determining attitudes and perspectives (McLeod, 2019). For the analysis of the data, the multi-criteria analysis (MCA) is used. This scientific evaluation method is discussed in detail in Appendix B. With a survey, data can be collected with which the level of social acceptance in different traffic scenarios can be determined.

5.4. Synopsis

This chapter described the first stage of the assessment method. The context and conditions are elaborated in which the assessment method can be used. When a researcher wants to determine whether a delivery robot can successfully be implemented in a traffic environment that consists of the factors listed in Table 5.1 and meets the pre-conditions stated in section 5.2, then the assessment method can be used. Furthermore, the factors to be assessed, identified during desk research, are listed accompanied by their indicators. This information is essential for the development of the two sub-methods of the assessment method. The performance factors can be assessed by performing a test-case and the social acceptance factors by means of a survey. The complete assessment method is described in the next chapter.

6
Assessment method

The assessment method is described in this chapter. The factors in the conceptual model created in chapter 4 underlie the choice of sub-methods used. The assessment method can be used by researchers who want to determine the level of roboreadiness of a traffic environment and agree with the description in chapter 5. The researcher should follow the steps described in the coming sections, which starts with specifying the traffic environment. Thereafter the test-case is reported and the template of the survey exposed. The data obtained with these two sub-methods, is analysed in the fourth section, which together lead to the determination of the roboreadiness of the traffic environment. The steps to be taken are first described in the main text of the sections, followed by a framework listing the actions at the end of each section. A synopsis of the assessment method closes this chapter.

6.1. Settings

Traffic environments consist of multiple traffic situations, which consist of the infrastructure factors listed in chapter 5, Table 5.1. The first step in the assessment method is to *verify which traffic situations are present in the traffic environment* that is considered in the research.

Each traffic situation has to deal with traffic conditions, also listed in chapter 5, Table 5.1. Some of these factors have a fixed value in a traffic situation, and some can differ at every moment. To be able to study the relation between the traffic environment and the performance and social acceptance, *settings have to be defined*. A setting is the traffic situation in combination with the related traffic conditions. Each setting can take on only one value of each traffic condition. This value should be chosen based on what is indicative for the setting. Each setting must be examined for performance and social acceptance in order to determine the level of roboreadiness. An overview of the settings can be made by filling in Table 6.1. The units to be filled in and replace the ‘x’ in the table can be found in chapter 5, Table 5.1.

Table 6.1: Characteristics of the settings.

Factor	Setting 1	Setting ..	Setting ..	Setting n
Infrastructure				
Width	x	x	x	x
Alignment	x	x	x	x
Crossings	x	x	x	x
Elevations	x	x	x	x
Traffic conditions				
Other road users	x	x	x	x
Intensity	x	x	x	x
Density	x	x	x	x
Visibility	x	x	x	x
Speed	x	x	x	x

Before executing the assessment method and obtaining results, the expected results should be thought of. This means *hypotheses can be formulated*. This could be about whether the traffic environment is roboready or not, or about the impact of the traffic environment on the performance of the robot and/or the social acceptance. This is dependent on the objective of the research.

Steps to design the settings:
- List the traffic situations that are present in the traffic environment
- Define settings
- Formulate hypotheses

6.2. Test-case

In each setting, the performance is to be examined by assessing the performance factors. Therefore, the *settings have to be created in real-life* first. If needed, to get the right values of the traffic conditions, people can be asked to help in the execution of the test-case. Instructions to walk around the delivery robot in a specific way and/or within a certain radius, can be given.

When the settings are prepared, *scenarios have to be created* by letting the delivery robot drive through the settings. It is called a scenario when the delivery robot is driving through the setting, from its begin to its end point. To start the trip of the robot, an order can be placed through the delivery service provider or a test run can be started. The routes in the traffic environment can cover one or more settings at once.

During the scenarios, the factors ‘pace’, ‘continuity’, ‘deviation’, ‘safety’ and ‘compliance’ are to be monitored. By means of observation, the researcher must *assess the indicators*. This involves counting the number of times the pace of the robot varies from the pace of the other road users, an unnecessary stop, an unnecessary deviation from the straight path, a collision or a violation of a traffic rule occurs within the scenario. These results can be filled in in the assessment matrix (see Table 6.2). The factors have to be assessed in every scenario.

Table 6.2: Assessment matrix for the performance factors for a scenario.

Scenario < x >

Factor / Iteration	**1**	**..**	**..**	**..**	**n**
Pace	x	x	x	x	x
Continuity	x	x	x	x	x
Deviation	x	x	x	x	x
Safety	x	x	x	x	x
Compliance	x	x	x	x	x

To be able to get an accurate result, *run the test-case 50 times*. This means n = 50, so 50 iterations have to be performed for each scenario. The reason behind this amount of iterations has to do with the fact that the delivery robot is a relatively new concept. It is important to collect a lot of data in order to check if the results are consistent and not based on coincidence.

Steps to perform the test-case:
- Create the settings in real-life
- Create scenarios by letting the robot drive through the settings
- Assess the indicators per scenario
- Run the test-case 50 times

6.3. Survey

With the survey the level of social acceptance can be determined in each scenario. The survey is compiled in Google Forms, since this is an easy to use platform for both the creator as the respondent. The template of the survey can be found in Appendix C.

The template has to be completed by the researcher for the traffic environment to be examined. To *finalise the survey*, various gaps have to be filled. In the survey, the respondent first gets information about the goal of the research and an explanation of the content of the survey. The image in the header can be changed if desired, and the introduction text can be expanded and/or specified. Dependent on the amount of scenarios, the number of minutes can be filled in. Then the respondent is asked whether he/she has interacted with the delivery robot at least once. This is done to check if the results can be used in the analysis, as the study is designed for actual experience and not for hypothetical. If the respondent answers ‘No’, the survey ends automatically.

Next, the factors ‘predictability’, ‘competence’, ‘comfort’ and ‘dimensions’ are explained. In order to determine the level of acceptance, the respondent has to divide a 100% between these factors, based on how much each factor determines the degree of acceptance for him/her. Then the factors have to be scored in each scenario. Therefore, page 3 in the template of the survey (see Appendix C, Figure C.3) has to be copied as many times as the amount of scenarios examined in the research. Each scenario has to be described first and can be supported by images of the setting or a video of the scenario. Per scenario the same factors are listed, which the respondent has to score on a scale of 1 to 5, based on importance of the factors during that scenario.

When the survey is ready, *distribute the survey*. The target audience should exist of the ‘average’ person in the environment. The group of respondents has to represent the people in the area, because those are the people who will have to deal with the delivery robot. The survey can be distributed online via social media platforms, or by stopping people on the streets and asking them to fill it in. Also, for example, a QR code can be placed on the robot, which can be scanned with a mobile phone and shows the survey online.

To get an accurate result, *the amount of respondents has to be at least 20% of the people in the area*. Not much is known yet in the field of research into the social acceptance of delivery robots, which makes the data valuable. Therefore, much data on the topic is desirable and needed in order to make solid statements.

Steps to conduct the survey:

- Finalise the survey
- Distribute the survey among a representative group
- Collect responses of at least 20% of the people in the area

6.4. Analysis

After obtaining the data from the test-case and the survey, it is time to analyse the results. With the analysis, the level of performance and the social acceptance can be determined, which together lead to the level of roboreadiness of the traffic environment. The data obtained in the test-case and survey, in combination with the results of the analysis should be stored in an open database. In this way researchers, public authorities and practitioners have access to the data, which can support future research and projects. When the data are saved in the same way every time the method is executed, this can avoid unnecessary research which could save time and money.

In this last part of the assessment method, the hypotheses formulated in the beginning are checked. The results of the test-case and the survey, leading to the level of roboreadiness, are discussed one-by-one in the next subsections.

6.4.1. Performance

The results from the test-case, as presented in the assessment matrix (Table 6.2), are a collection of observations. For all scenarios a matrix should have been created showing 50 values for all five factors. The first step in the analysis of the results is to *summarise the data using descriptive statistics*. For each scenario, the sum, mean, standard deviation (SD) and variance (VAR) should be calculated for all factors. These values can be filled in in Table 6.3.

Table 6.3: Descriptive statistics and significance level per factor per scenario.

Scenario < x >						
	Sum	**Mean**	**SD**	**VAR**	**t-score**	**p-value**
Pace	x	x	x	x	x	x
Continuity	x	x	x	x	x	x
Deviation	x	x	x	x	x	x
Safety	x	x	x	x	x	x
Compliance	x	x	x	x	x	x

With the overview of the results, it is possible to carry out a statistical analysis. Using the mean and standard deviation, *a one-sample t-test can be performed*. This test makes it possible to analyse whether the sample mean differs significantly from a specific value, the hypothesised value. The t-test does not have to be performed for factors where the variance is 0, because in this case it can already be concluded that the mean does not differ from 0. To use the one-sample t-test, the data must meet certain conditions. The dependent variable is assumed to be normally distributed and the data have to be independent (Gerald, 2018). Both assumptions are met in this research, since the sample has enough observations (n=50) and all data are obtained in different runs. The formula of the one-sample t-test is as follows:

$$t = \frac{\overline{x} - \mu}{\hat{\sigma}/\sqrt{n}} \tag{6.1}$$

Where:

- $\overline{x}$ is the mean
- μ is the hypothesised value
- $\hat{\sigma}$ is the standard deviation
- n is the number of iterations

The outcome of this equation is a t-score, which has to be translated to a p-value. This can be done using an online p-value calculator, or looking up the score in the t-distribution table. The degrees of freedom equals $n - 1$, and the t-test is one-tailed (since it is tested whether the mean is bigger than 0, not less). The t-score and p-value should be added in Table 6.3. A p-value less than .05 is considered to be statistically significant in this research.

In this research, the mean of all iterations of a factor should be compared to 0 ($\mu = 0$), to examine whether this differs significantly. This is because 0 is the optimal value, it equals the best possible performance score. To reach a good level of performance, the robot should not deviate from the speed of other road users, should not stop unnecessarily, should not deviate from the straight path, should not collide and should not break traffic rules. Every time this does happen, it has a negative impact on the performance. Therefore, the height of the score is negatively related to the level of performance.

The outcomes of the descriptive statistics and of the one-sample t-test make it possible to *interpret the results*. With the variance of the values of the iterations per factor within a scenario, the spread of the data points can be evaluated. It shows the extent to which the values differ from each other. With a higher variance, the spread is greater and the values deviate more from the mean. In that case, the value of the indicator of the factor is not consistent, which means that one should be careful when drawing conclusions. The outcome of the one-sample t-test states whether the mean is significantly different from the optimal value 0. If this difference is significant, this means that the mean of the iterations of the factor is different than 0 and thus the level of performance is not optimal. If the difference is not significant, it means the mean does not significantly deviates from 0 which is beneficial for the performance.

It is interesting to compare the factors with each other within the scenarios. This gives an idea of how the factors score relative to each other. Moreover, the scenarios can be compared with each other to see whether or not there are major differences. A bar chart of the different scenarios can be made for visual support, to see at a glance in which scenario certain factors occur more often than in others.

One more step before the level of performance can be determined is to *check if the data meet the minimum requirements*. It can occur that some values are not acceptable because they are too unsafe in themselves. In this case, the scenario has an insufficient level of performance and further analysis is excluded. The requirements are:

- Safety = 0
- Pace, continuity, deviation, compliance <= 25

Safety has to be 0 in every iteration. It must not happen that the robot collides, otherwise the performance is insufficient by definition. Additionally, the sum of the remaining factors must not be greater than 25 per factor. This means that per factor, the indicator may happen on up to half of the iterations.

If the data of the scenarios meet the minimum requirements, it is time to *translate the scores to the level of performance*. The factors within a scenario do not weigh the same, since the consequences of a traffic rule violation are bigger than of a deviation from the pace of other road users/an unnecessary stop/an unnecessary deviation from the straight path. Therefore, the sum of the iterations of the factor compliance has to be multiplied by 10. The sum of the factors in a scenario is the performance score. The lower this score the better, as it means that incidents happen less frequent. There are four different levels: good, sufficient, insufficient and bad. The performance score determines the level of performance. A score between 0 and 25 represents a good level of performance. For a sufficient performance, the score has to be between 26 and 50. When the score is 51 up to 75 the performance is insufficient. With a score of 76 till 100 the performance is bad. The levels and corresponding scores are listed in Table 6.4.

Table 6.4: Levels of performance.

Performance level	Performance score
Good	0 - 25
Sufficient	26 - 50
Insufficient	51 - 75
Bad	76 - 100

A distinction is made between insufficient and bad, because with an insufficient level of performance there is still room for improvement. The level of performance can be close to a sufficient level. However, with a bad level of performance, the setting is not suitable for delivery robots and has no potential to become one.

With the level of performance per setting, it is possible to *check the hypothesis*, if a hypothesis was formulated about the performance of the settings.

Steps to analyse the performance:

- Summarise the data using descriptive statistics
- Perform a one-sample t-test to determine whether the mean is significantly different from 0
- Interpret the results
- Check if the data meet the minimum requirements
- Translate the scores to the level of performance

(- Check the hypothesis)

6.4.2. Social acceptance

The collection of the survey responses forms the data of social acceptance. The purpose of the survey is to obtain data to examine the influence of the traffic environment on the level of social acceptance. Therefore, *the results should be summarised per scenario*. The results that should be presented, are the acceptance scores of each scenario per respondent.

The distribution in percentages of the factors for the level of acceptance, is the weight the respondent gives to the factors. The values from 1 to 5 on a Likert scale that the respondent gives to the factors in each setting, are the scores. To come to the acceptance score of a setting, multiply the weight of a factor by the score of that factor within that setting, and add up the multiplications of all factors. The acceptance score of each setting, per respondent, can be displayed as in Table 6.5.

Table 6.5: Table for acceptance scores per respondent per scenario.

	Scenario 1	**Scenario ..**	**Scenario ..**	**Scenario n**
Resp 1	x	x	x	x
Resp ..	x	x	x	x
Resp ..	x	x	x	x
Resp ..	x	x	x	x
Resp n	x	x	x	x
Average	*x*	*x*	*x*	*x*

It is interesting to analyse the spread of the data, to check whether there is unanimity among the respondents. This can be done by zooming in on the scenarios and looking to the spread within the factors individually. Therefore, *the variance of the weighted scores has to be calculated.* The percentage (weight) given to a factor by a respondent, has to be multiplied by the score given to that factor, for every scenario. For these weighted scores the variance needs to be calculated per factor. The table to fill in these results is given in Table 6.6.

Table 6.6: Variances of the weighted scores of the respondents per factor within a scenario.

Scenario < x >

	Resp 1	**Resp ..**	**Resp ..**	**Resp ..**	**Resp n**	***VAR***
Predictability	x	x	x	x	x	*x*
Competence	x	x	x	x	x	*x*
Comfort	x	x	x	x	x	*x*
Dimensions	x	x	x	x	x	*x*

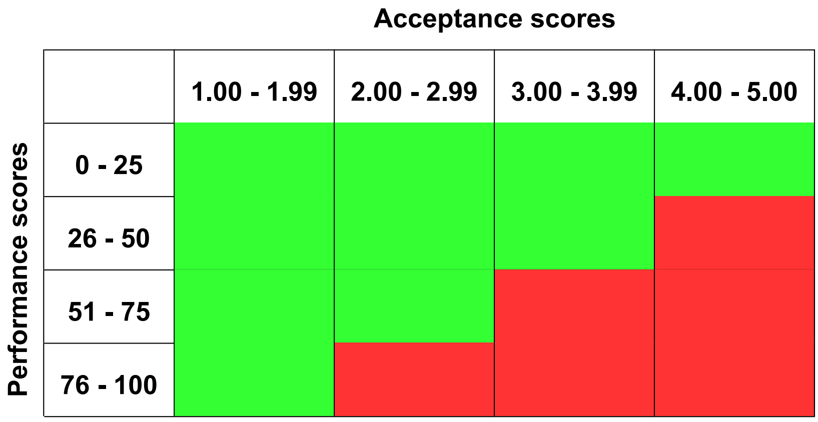
The overviews of the acceptance scores per scenario and the variances per factor can be used to *interpret the results*. If the acceptance score in a scenario is high, it means that in that scenario people accept the delivery robot less quickly than if the acceptance score is low. The reason for this is that people consider the factors to be of higher importance. With a low acceptance score, people accept the delivery robot faster. People care less about the value of the indicator of the factor. This has thus to do with the performance of the robot.

It can be valuable to analyse the spread behind the acceptance scores. If the spread within a factor is high, this means there is less unanimity from the respondents. It could be that that factor is less related to the acceptance than if the variance is lower. With a low variance, respondents score the factor more equally, which could show an effect between the factor and the acceptance. However, no firm conclusions can be drawn. More research would be necessary to check for example the correctness of the question or the accuracy of the description of the scenario.

In order to *translate the scores to the level of social acceptance*, the acceptance scores have to be linked to the level of performance, determined in the test-case. With a higher acceptance score, it is more important that the performance of the robot is good, to ensure acceptance. With a low performance, people accept the robot less quick, because the value of the indicators is important. When the acceptance score is lower, an inferior performance level can be tolerable for people to accept the robot. Hence, whether the robot is accepted in the scenario, depends on the performance in that scenario.

Table 6.7 shows the acceptance score bandwidths linked to the level of performance, hereby expressing when acceptance is the case. If the robot is accepted in the scenario, this means the performance of the robot is good enough given the acceptance score. In the table this can be read by checking the box of the relevant acceptance score and the performance score of that scenario. When the box is green, it means the robot is accepted given the performance. If the colour of the box is red, this means the robot in not acceptance in that scenario with the given performance.

Table 6.7: The acceptance scores linked to the performance scores (green = acceptance, red = no acceptance).



Based on the outcomes of the analysis, the researcher can *check the hypothesis*, if this was formulated about the social acceptance of the settings.

Steps to analyse the social acceptance:
- Summarise the results per scenario
- Calculate the variance of the weighted scores of the respondents per factor within a scenario
- Interpret the results
- Translate the scores to the level of social acceptance

(- Check the hypothesis)

6.4.3. Roboreadiness

The level of performance and the level of social acceptance are defined per setting. These outcomes together, determine the level of roboreadiness of the traffic environment. For the traffic environment to be roboready, the performance and acceptance have to reach a minimal level. Therefore, the first step in the analysis of the roboreadiness is to *check whether the performance and acceptance requirements are met*. The performance has to have a maximum score of 50 in all settings. Above this score, the performance is insufficient and thus the traffic environment not suitable. Furthermore, in all settings the robot has to be accepted in order for the traffic environment to be roboready. As can be seen in Table 6.7, if the acceptance score in a scenario is above 4.00 and the performance score is between 25 and 50, the robot is not accepted. In this case the traffic environment is not roboready.

Now that it is clear when the traffic environment is roboready, it is time to *translate the results to the level of roboreadiness*. The degree of readiness of the traffic environment for delivery robots to drive there, is negatively correlated with the performance and acceptance scores. The lower the performance score in the scenarios, the more roboready the traffic environment is. The lower the acceptance score of people in the scenarios, the faster they accept the robot, so the more roboready the traffic environment is. It is assumed that the performance and acceptance scores have the same weight, so the aspects both count for 50%. In that case, the levels of roboreadiness can be divided as shown in Table 6.8. The different colours stand for the different levels. Purple implies that the traffic environment is very roboready and magenta means roboready. Pink indicates not (far from) roboready, whereas the light pink means far from roboready.

Table 6.8: Levels of roboreadiness (purple = very roboready, magenta = roboready, pink = not roboready, light pink = far from roboready).

		Acceptance scores			
		1.00 - 1.99	2.00 - 2.99	3.00 - 3.99	4.00 - 5.00
Performance scores	0 - 25				
	26 - 50				
	51 - 75				
	76 - 100				

For every setting, the level of roboreadiness has to be determined. The average of the sum of these levels is the level of roboreadiness of the traffic environment. This only applies if all settings individually have sufficient levels of performance and social acceptance.

With the level of roboreadiness, it is possible to *check the hypothesis*, if this was formulated about the roboreadiness of the traffic environment.

Steps to analyse the roboreadiness:

- Check whether the performance and acceptance requirements are met
- Translate the results to the level of roboreadiness
(- Check the hypothesis)

6.5. Synopsis

This chapter described the second stage in the development of the assessment method, and presented the actual assessment method. The main steps include designing the settings, performing the test-case, conducting the survey and analysing the results. By executing the two sub-methods, data about the performance and social acceptance can be obtained. Analysing these results should lead to an answer to the question whether the traffic environment is suitable for implementation of delivery robots. For an overview of all actions of the assessment method, Appendix D can be consulted.

7
Validation

The assessment method described in the previous chapter is executed on a small scale to validate the method and to serve as a demonstration. This chapter describes the execution of all actions of the assessment method. The findings are presented, which gives a first impression of the robot's functioning in the traffic environment at the campus of the Erasmus University Rotterdam. In the second section, a conclusion about the validation follows.

7.1. Execution

In this section the steps of the assessment method are followed, as part of the validation. The traffic environment studied in this research, is located at the campus of the Erasmus University Rotterdam. This location is chosen because this is the only place in the Netherlands where a delivery robot is driving. The coming subsections discuss the steps of the assessment method, starting with specifying the settings. Then the execution of the test-case and the survey are described. An analysis of the results ends this section.

7.1.1. Settings

List the traffic situations that are present in the traffic environment.

The delivery robot at the campus drives two routes. These are illustrated on the map of the campus, in chapter 1, Figure 1.3. On these routes there are four main traffic situations. On the route from Spar to Library, the delivery robot encounters a narrow road surrounded by pillars, a wide road that goes straight, and a road narrowing where the road starts going downhill. On the route from Spar to Hatta Building, an extra traffic situation that the robot faces is a bend in the road.

Define settings.

The four traffic situations are used to create four settings, which are used in the test-case and the survey. In these settings, the infrastructure factors and most traffic conditions are a given. However, some traffic conditions can take different values. For these conditions the most indicative value is chosen. An overview of the characteristics of all settings is presented in Table 7.1. Each setting is described after. Pictures of the settings can be found in Appendix E. Due to privacy reasons, the persons in the settings are shown in drawings.

Table 7.1: Characteristics of the settings.

Factor / Setting	1: Basis	2: Pillars	3: Road narrowing	4: Bend
Infrastructure				
Width	Wide	Narrow	Wide to narrow	Wide
Alignment	Straight	Straight	Straight	Curve
Crossings	No	Yes	No	Yes
Elevations	Flat	Flat	Downhill	Flat

Table 7.1: Characteristics of the settings.

Factor / Setting	1: Basis	2: Pillars	3: Road narrowing	4: Bend
Traffic conditions				
Other road users	Pedestrians	Pedestrians	Pedestrians	Pedestrians
Intensity	5 persons	4 persons	5 persons	3 persons
Density	$28m^2$	$10m^2$	$17m^2$	$28m^2$
Visibility	100%	40%	75%	100%
Speed	4 km/h	4 km/h	3 km/h	4 km/h

Setting 1: Basis
The first setting is the base setting. The road is wide, goes straight, has no crossings and is flat. The other road users are pedestrians, who are walking at a steady walking speed. The indicative value of the intensity is five persons in a radius of five metres around the delivery robot. The density is low, which means there is much free space around the robot. The visibility is good, the robot can see far around. A visualisation of setting 1 is given in Appendix E, Figure E.1.

Setting 2: Pillars
In the second setting the delivery robot drives through a narrow lane, surrounded by pillars. This makes that the robot can not see around the corner. The road is flat and goes straight, but the robot faces a crossing when it passes the pillars. The other road users consist of pedestrians only, with an intensity of four persons in a radius of five metres around the delivery robot, walking approximately 4 kilometres per hour. There are many obstacles around (the pillars) so the density is high. This makes that the view the robot has does not reach far. Setting 2 is illustrated in Appendix E, Figure E.2.

Setting 3: Road narrowing
In the third setting the delivery robot encounters a road narrowing and the road goes downhill. There are no crossings and the road goes straight. Again the robot only encounters pedestrians, five persons in a radius of five metres, who are walking with a speed of around 3 kilometres per hour. The density goes from low to high, as the road approaches a path between bushes, coming from an open square. The field of vision is good, because the bushes are low. An image of setting 3 is shown in Appendix E, Figure E.3.

Setting 4: Bend
The fourth setting contains a bend in the road, where the delivery robot goes to the right on a crossing. Moreover, the road is wide and flat. Pedestrians are the only other road users: there are 3 persons around the delivery robot, in a radius of five metres, walking at a steady walking speed. The density is low, there are no obstacles around and therefore the visibility is good. Setting 4 is depicted in Appendix E, Figure E.4.

Formulate hypotheses.
The goal within this validation is to investigate whether the traffic environment at the campus of the Erasmus University Rotterdam is roboready. By defining the levels of performance and social acceptance in different settings, this can be determined.

The hypothesis in this validation research is: “The traffic environment at the campus of the Erasmus University Rotterdam is roboready.”

7.1.2. Test-case

Create the settings in real-life.
In order to assess the performance factors in the four settings described above, a group of five students is asked to help create the settings. Instructions are given to walk around the delivery robot, within approximately five metres, on walking speed.

Create scenarios by letting the robot drive through the settings.
To let the delivery robot drive, an order is placed via the SPAR university application. First, the destination chosen is Library. On the way from SPAR to Library, the robot passes by setting 1, 2, and 3. Thereafter, the second route is driven, by ordering groceries with destination Hatta Building. During this trip, the robot drives through setting 2 and 4.

Assess the indicators per scenario.
The performance factors are monitored between the begin and the end point of the setting. The factors are assessed during the length of the scenario. Scenario 1, 2 and 3 are monitored during the trip from SPAR to Library. Scenario 4 is monitored during the trip from SPAR to Hatta Building. The assessment matrices for the scenarios are filled in. The results can be seen in Table 7.2.

Table 7.2: Results of the assessment of the performance factors per scenario.

(a) Scenario 1: Basis.

Factor / Iteration	**1**	**2**	**3**	**4**	**5**
Pace	1	0	1	0	0
Continuity	0	0	1	0	0
Deviation	0	0	1	0	1
Safety	0	0	0	0	0
Compliance	0	0	0	0	0

(b) Scenario 2: Pillars.

Factor / Iteration	**1**	**2**	**3**	**4**	**5**
Pace	0	0	0	1	1
Continuity	1	0	0	1	0
Deviation	0	0	1	0	1
Safety	0	0	0	0	0
Compliance	0	0	0	0	0

(c) Scenario 3: Road narrowing.

Factor / Iteration	**1**	**2**	**3**	**4**	**5**
Pace	0	1	0	1	0
Continuity	0	0	0	0	0
Deviation	0	0	0	0	2
Safety	0	0	0	0	0
Compliance	0	0	0	0	0

(d) Scenario 4: Bend.

Factor / Iteration	**1**	**2**	**3**	**4**	**5**
Pace	0	1	1	0	0
Continuity	0	0	0	0	0
Deviation	0	0	0	0	0
Safety	0	0	0	0	0
Compliance	0	0	0	0	0

Run the test-case 50 times.
For the validation of the method, the test-case is performed on a small scale. In this way a first impression on the robustness of the method can be obtained. This, in combination with limited time, makes that the test-case is executed five times.

7.1.3. Survey

Finalise the survey.
The template in Appendix C, described in chapter 6, section 6.3, is used to create the survey for the traffic environment at the campus of the Erasmus University Rotterdam. The image in the header of the survey is changed to a picture of the delivery robot driving at the campus. Moreover, the introduction text on the first page of the survey template, Figure C.1, is specified for this research. Since four scenarios are used in the validation, page 3, seen in Figure C.3, is copied four times. For all scenarios a description is given in terms of infrastructure and traffic conditions, and visualisations are added. The completed survey can be found in Appendix F.

Distribute the survey among a representative group.
The survey is distributed in two different ways. Via WhatsApp the link to the survey is shared with a group of people studying at the Erasmus University Rotterdam. People who have seen the robot in operation are invited to fill in the survey. In addition, QR codes are printed which are linked to the survey online. These are handed out on campus, to people standing around the robot while in operation.

Collect responses of at least 20% of the people in the area.
For the validation of the method 10 responses are obtained. This is less than 20% of people in the area, which is due to limited time. Nevertheless, with these data first insights can be gained.

7.1.4. Analysis

The findings of the test-case and the survey are presented and analysed in this subsection. These results lead to the level of roboreadiness of the traffic environment at the campus of the Erasmus University Rotterdam, described at the end.

Performance

Summarise the data using descriptive statistics.

The data obtained during the test-case resulted in 5 values per factor per scenario. Since the instruction was to run the test-case 50 times, the data is multiplied by 10. In this way the analysis can be performed in the right way. The assumption is made that running the test-case 5 times gives similar results as running the test-case 50 times. The descriptive statistics of the factors in scenario 1, 2, 3 and 4 are summarised in Table 7.3, Table 7.4, Table 7.5 and Table 7.6, respectively.

Table 7.3: Descriptive statistics of the factors in scenario 1: Basis.

	Sum	Mean	SD	VAR	t-score	p-value
Pace	20	0.40	0.49	0.24	5.72	.0000
Continuity	10	0.20	0.40	0.16	3.50	.0005
Deviation	20	0.40	0.49	0.24	5.72	.0000
Safety	0	0.00	0.00	0.00	-	-
Compliance	0	0.00	0.00	0.00	-	-

Table 7.4: Descriptive statistics of the factors in scenario 2: Pillars.

	Sum	Mean	SD	VAR	t-score	p-value
Pace	20	0.40	0.49	0.24	5.72	.0000
Continuity	20	0.40	0.49	0.24	5.72	.0000
Deviation	20	0.40	0.49	0.24	5.72	.0000
Safety	0	0.00	0.00	0.00	-	-
Compliance	0	0.00	0.00	0.00	-	-

Table 7.5: Descriptive statistics of the factors in scenario 3: Road narrowing.

	Sum	Mean	SD	VAR	t-score	p-value
Pace	20	0.40	0.49	0.24	5.72	.0000
Continuity	0	0.00	0.00	0.00	-	-
Deviation	20	0.40	0.81	0.65	3.50	.0005
Safety	0	0.00	0.00	0.00	-	-
Compliance	0	0.00	0.00	0.00	-	-

Table 7.6: Descriptive statistics of the factors in scenario 4: Bend.

	Sum	Mean	SD	VAR	t-score	p-value
Pace	20	0.40	0.49	0.24	5.72	.0000
Continuity	0	0.00	0.00	0.00	-	-
Deviation	0	0.00	0.00	0.00	-	-
Safety	0	0.00	0.00	0.00	-	-
Compliance	0	0.00	0.00	0.00	-	-

Perform a one-sample t-test to determine whether the mean is significantly different from 0.

A one-sample t-test is performed for all factors with a variance not equal to 0. Equation 6.1, stated in chapter 6, is used where $\overline{x}$ is the mean of the factor, μ is 0, $\hat{\sigma}$ is the standard deviation of the factor, and n is 50. With this information the t-scores are calculated in Excel. These scores are translated to p-values, using an online calculator. The results are given in Table 7.3, Table 7.4, Table 7.5 and Table 7.6. All p-values are less than .05, which means all results are significant.

Interpret the results.
With the variances it is possible to get insights into the spread of the data. The p-values could give an impression of effects on the level of performance. Since the data is based on 5 iterations and multiplied by 10, there is not much difference between the results. Looking at the variances besides 0, most have a value of 0.24 in combination with a mean of 0.40. A remarkable result is that the mean of the factor deviation in scenario 3 also has a value of 0.40, but a higher variance (0.65). The reason is that in the data set, the value 2 occurs while this is not the case with the other factors. This means this factor has a higher spread than the others. The t-test served as a verification to check whether the means are really greater than 0. The p-values of all factors with a variance higher than 0, are less than .05, which means all these results are significantly different from 0.

A bar chart is made for visualisation to see in which scenario certain factors occur more often than in others. This can be seen in Figure 7.1.

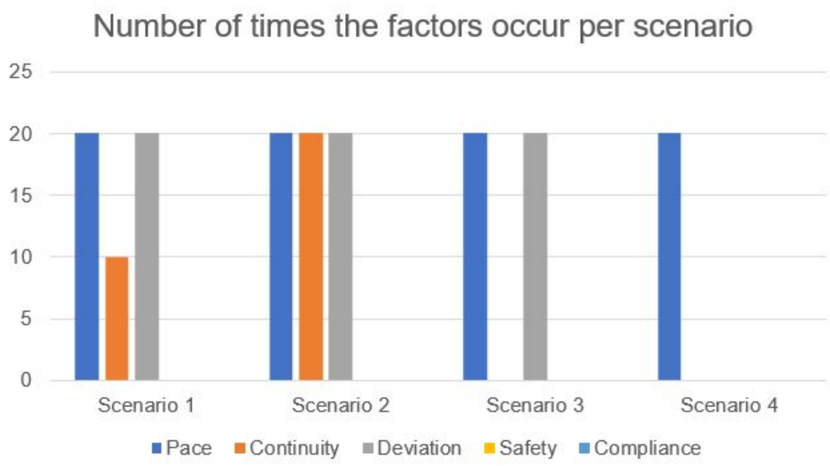


Figure 7.1: Number of times the factors occur per scenario.

The results in the chart are fairly self-explanatory, since it is based on only 5 different iterations. As can be seen, the factors safety and compliance do not occur in any scenario. In scenario 4 only the factor pace occurs. This means that the robot does not have the same pace as other traffic participants in all iterations, but that the other performance factors have an optimal value.

Check if the data meet the minimum requirements.
Before the results are translated to the level of performance, the minimum requirements are checked. In all iterations in all scenarios, the value of safety in 0. The robot has not collided during the test-case. Looking at the sum of the iterations per factor in each scenario, shows that no value exceeds 25. Hence, the minimum requirements of the data are met.

Translate the scores to the level of performance.
The factor compliance has a value of 0 in all iterations. The robot has not broken any traffic rules. This means the sums of the factors within a scenario are summed up. This leads to the performance score of 50 in scenario 1, 60 in scenario 2, 40 in scenario 3 and 20 in scenario 4. Consulting Table 6.4 in chapter 6, this leads to the following levels of performance of the settings:

- Setting 1: Basis — **Sufficient** level of performance
- Setting 2: Pillars — **Insufficient** level of performance
- Setting 3: Road narrowing — **Sufficient** level of performance
- Setting 4: Bend — **Good** level of performance

Check the hypothesis.
In this validation research, no hypothesis was formulated on the performance specifically.

Social acceptance
Summarise the results per scenario.
For a complete overview of the results of the survey, Appendix G can be consulted. In Figure G.1, the data per respondent is displayed. This is converted into an overview of the acceptance scores (weight times score) per respondent per scenario, which can be seen in Table 7.7.

Table 7.7: The acceptance scores per respondent per scenario.

	1: Basis	2: Pillars	3: Road narrowing	4: Bend
Resp 1	4.65	4.25	3.60	3.15
Resp 2	3.85	3.70	3.60	4.20
Resp 3	3.40	4.00	4.70	4.30
Resp 4	3.50	4.20	4.50	2.80
Resp 5	3.30	3.30	3.50	3.50
Resp 6	4.20	4.50	4.60	3.70
Resp 7	4.70	3.95	4.30	4.00
Resp 8	4.20	4.40	4.70	5.00
Resp 9	3.50	3.90	3.85	2.50
Resp 10	3.90	3.30	3.80	3.90
Average	*3.92*	*3.95*	*4.12*	*3.71*

Calculate the variance of the weighted scores of the respondents per factor within a scenario.
Variances are calculated to check the distribution of the data. The degree of spread can have consequences on the interpretation of the results. To analyse the spread, the weighted scores per factor within a scenario are calculated first. This is done in Excel, by multiplying the weight with the score of the factor, for each factor in each scenario. Thereafter, the variance of the factors is calculated. The results are presented in Table 7.8, Table 7.9, Table 7.10 and Table 7.11.

Table 7.8: Variances of the factors in scenario 1: Basis.

Factor / Resp	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***VAR***
Predictability	1.50	1.50	0.60	1.00	1.20	2.00	1.20	0.80	1.00	1.50	*0.17*
Competence	0.60	0.90	1.20	1.50	0.90	0.30	1.75	1.20	1.00	0.60	*0.19*
Comfort	1.75	0.45	1.20	0.60	0.40	0.30	0.00	1.00	1.05	1.60	*0.33*
Dimensions	0.80	1.00	0.40	0.40	0.80	1.60	1.75	1.20	0.45	0.20	*0.28*

Table 7.9: Variances of the factors in scenario 2: Pillars.

Factor / Resp	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***VAR***
Predictability	1.50	1.20	0.80	0.60	0.90	2.00	1.50	1.00	1.00	1.50	*0.18*
Competence	0.75	0.90	1.20	2.50	1.20	0.40	1.40	1.20	1.25	0.60	*0.33*
Comfort	1.40	0.60	1.20	0.60	0.60	0.10	0.00	1.00	1.05	0.80	*0.20*
Dimensions	0.60	1.00	0.80	0.50	0.60	2.00	1.05	1.20	0.60	0.40	*0.22*

Table 7.10: Variances of the factors in scenario 3: Road narrowing.

Factor / Resp	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	***VAR***
Predictability	1.50	1.20	1.00	1.00	1.20	2.00	1.50	1.00	1.00	1.50	*0.11*
Competence	0.45	1.20	1.50	2.50	0.90	0.50	1.75	1.20	1.00	0.40	*0.43*
Comfort	1.05	0.45	1.20	0.80	0.80	0.10	0.00	1.00	1.40	1.60	*0.28*
Dimensions	0.60	0.75	1.00	0.20	0.60	2.00	1.05	1.50	0.45	0.30	*0.31*

Table 7.11: Variances of the factors in scenario 4: Bend.

Factor / Resp	1	2	3	4	5	6	7	8	9	10	*VAR*
Predictability	0.90	1.50	1.00	0.40	1.20	1.20	1.20	1.00	0.75	1.50	*0.11*
Competence	0.45	1.50	1.50	1.50	0.90	0.40	1.40	1.50	0.75	0.60	*0.23*
Comfort	1.40	0.45	1.20	0.60	0.80	0.10	0.00	1.00	0.70	1.60	*0.28*
Dimensions	0.40	0.75	0.60	0.30	0.60	2.00	1.40	1.50	0.30	0.20	*0.38*

Interpret the results.
For the goal of the research, the acceptance score per scenario is important because this determines the social acceptance of the traffic environment. Therefore, the average acceptance scores per scenario are added to Table 7.7. The results show that the acceptance score is the highest in scenario 3 (4.12) and the lowest in scenario 4 (3.71). This means that people accept the delivery robot the fastest in scenario 4 and the least fast in scenario 3. This is because in the latter scenario the factors are considered more important in the determination of the acceptance. Thus, in scenario 3 it is more important that the delivery robot performs well on those factors. The acceptance scores of scenario 1 and 2 are very close to each other (3.92 & 3.95), whereby scenario 2 has a slightly higher score.

Looking at the variances of the factors within the scenarios, the highest variances can be found in scenario 3. This implies that in the road narrowing setting, respondents agree the least with each other. There is less unanimity than in other scenarios. Furthermore, in every scenario the factor predictability has the lowest variance, and thus the least spread.

Translate the scores to the level of social acceptance.
To be able to determine the level of social acceptance, the acceptance scores are linked to the performance scores determined in the analysis of the test-case results. To keep the overview, the acceptance and performance scores are listed per setting:

Setting 1: Basis	Acceptance score	3.92	Performance score	50
Setting 2: Pillars	Acceptance score	3.95	Performance score	60
Setting 3: Road narrowing	Acceptance score	4.12	Performance score	40
Setting 4: Bend	Acceptance score	3.71	Performance score	20

With the given performance factors, Table 6.5 in chapter 6 can be consulted. The settings are put in the corresponding boxes, to check the status of the acceptance with the given performance score. This is illustrated in Table 7.12.

Table 7.12: The acceptance scores linked to the performance scores (green = acceptance, red = no acceptance).

Acceptance scores

Performance scores	**1.00 - 1.99**	**2.00 - 2.99**	**3.00 - 3.99**	**4.00 - 5.00**
0 - 25			Setting 4	
26 - 50			Setting 1	Setting 3
51 - 75			Setting 2	
76 - 100				

This leads to the level of social acceptance per setting, as listed below:

- Setting 1: Basis — Social acceptance **is achieved**
- Setting 2: Pillars — Social acceptance **is not achieved**
- Setting 3: Road narrowing — Social acceptance **is not achieved**
- Setting 4: Bend — Social acceptance **is achieved**

Check the hypothesis.
In this validation research, no hypothesis was formulated on the social acceptance specifically.

Roboreadiness
Check whether the performance and acceptance requirements are met.
For the traffic environment to be roboready, there are two requirements that have to be met. The performance and acceptance both have to reach a minimal level. The performance must not have a score of over 50, to have a sufficient level of performance. Setting 2 does not meet this requirement, since it has a performance score of 60 meaning an insufficient level of performance. The other settings do meet this requirement. Moreover, social acceptance has to be achieved in all settings. In setting 2 and 3 this is not the case. The performance is too bad to achieved social acceptance. Setting 1 and 4 do meet this requirement.

Translate the results to the level of roboreadiness.
Since the requirements are not met in all settings, it can be stated that based on the results of the assessment method, the traffic environment is not roboready. The related levels have to be examined to be able to come to the overall level of non-roboreadiness.

Two of the settings fall in the box ‘not roboready’, one in the box ‘roboready’ and on in the box ‘very roboready’. This means the level of roboreadiness of the traffic environment at the campus of the Erasmus University Rotterdam is **not** (far from) **roboready**.

Check the hypothesis.
The performance and acceptance do not reach the minimal levels in order to state that the traffic environment is roboready. Based on the results of this validation research, the traffic environment at the campus of the Erasmus University Rotterdam seems not to be roboready. Therefore, the hypothesis in this validation research: “The traffic environment at the campus of the Erasmus University Rotterdam is roboready.” can not be accepted.

7.2. Conclusion

The last part of the development of the assessment method, was the validation of the method. This is done by performing the method, to demonstrate whether it is suitable for the intended purpose. This purpose is to be able to determine the level of roboreadiness of a traffic environment, by assessing the performance and social acceptance in different settings.

With a test-case the performance is assessed, and by means of a survey the social acceptance is determined. These outcomes together made it possible to state the level of roboreadiness of the traffic environment. This is in line with the objectives, and therefore the assessment method is valid. With the method it is possible to examine what should be examined. Hence, this chapter answers the second sub-question: *“What kind of methods can be used to assess these factors?”*

8
Discussion

This chapter contains a discussion of the proposed assessment method. In the first section a reflection is carried out to suggest improvements for the assessment method, based on the validation. In the second section, the first findings from the pilot with the delivery robot at the Erasmus University Rotterdam are discussed. The third and fourth section reflect on the usefulness of the research, by elaborating on the implications and the limitations, respectively.

8.1. Assessment method

The purpose of the method is to be able to determine the level of roboreadiness of a traffic environment. This method has been validated as part of the development of the assessment method, to check whether it does what it is supposed to do. Besides that, the validation serves as a demonstration of the method. From this validation a number of things emerges that might need to be changed or added. This section therefore reflects on the results of the validation.

It was stated that based on the levels of performance and social acceptance, the level of roboreadiness of a traffic environment can be determined. For the validation, the steps of the assessment method were executed at the traffic environment at the campus of the Erasmus University Rotterdam. Although the hypothesis of the research could not be accepted, assessing the factors and translating the scores to the levels of performance and social acceptance were successful and the results were realistic. Therefore, the purpose of the method has been achieved, which makes that the method is valid.

However, this is a first concept so there is room for improvement. A number of things did come to light during implementation. Performing the test-case costs a lot of time, since assessing the factors is based on counting. The main point of improvement is to use data from the robot instead of obtaining data by means of observations. However, this may not always be possible.

The proposed assessment method can only be used for traffic environments consisting of the factors covered in the infrastructure and traffic conditions included for this method. It is not tested whether this method can be used if other factors occur. Furthermore, the method is limited to five factors that determine performance in a traffic environment and four factors that determine social acceptance in the traffic environment, based on literature study. However, practice might show that others factors are also relevant and should be added to the method.

Zooming in on the factors, pace and deviation are assessed by counting how often the robot deviates from the pace of other traffic participants and how often the robot deviates from the straight path. It is not considered to what extent or for how long, which could also be important and may lead to other results. Additionally, the seriousness of a collision or a violation matters in real-life, but is not included in the method. Furthermore, the three performance factors pace, continuity and deviation carry equal weight in the determination of the level of performance. It does not necessarily have to be the case that these factors are equally important. Research can be conducted into the consequences when the factors occur, or the user of the method can assign weights to the factors at their discretion. Likewise, in defining the level of roboreadiness the performance and acceptance scores are weighted equally. This means that both have an equal share in the determination of the roboreadiness. Nevertheless, it could be the case that one of them is more important and should have a higher weight than 50%.

In the survey, respondents are asked to weigh and score the social acceptance factors per scenario. For the analysis of the results the multi-criteria analysis is used. However, since there are no objective metrics available to evaluate the social acceptance, the Best-Worst Method (BWM) could be another option to use (Rezaei, n.d.). This uses pairwise comparison, instead of only giving weights to the factors and score them individually. In case the BWM is used, respondents have to be asked in the survey what they find the best and the worst factor, and then score all factors relative to these two. This leads to the weights belonging to the factors in the determination of the social acceptance.

Despite the aspects that could be improved, the proposed assessment method is a step in the right direction. With a novelty in the research area, there must always be a beginning. This thesis lays a foundation, and highlights important experiences and outcomes.

8.2. First findings

During the validation of the method, the test-case was executed and the survey distributed. Even though it was performed on a small scale, data about the performance and the social acceptance were obtained. The steps of the analysis were followed, which led to the levels of performance, social acceptance and roboreadiness of the traffic environment. These results can serve as the first insights regarding the delivery robot in this environment. Therefore, this section reflects on the findings.

The delivery robot was driving for some months already, before this validation took place. Therefore, experience could tell this area seemed to ensure a good performance of the robot and acceptance by bystanders, which is the reason of the formulation of the hypothesis. The delivery robot has been monitored on a weekly basis, to keep an eye on the operation. This showed that the robot sometimes had to face challenges. It is unrealistic for new technologies to function properly at all times in the early stages of development. This can affect the results regardless of the characteristics of the traffic environment. Nevertheless, the results of the validation of the assessment method could reflect reality. Setting 1 and 4 have a sufficient and good level of performance and the robot is accepted. These settings include the basis and the bend. Both traffic situations are spacious which means that robot and people can pass easily, there are no obstacles in the way. In setting 3 the performance is sufficient, so the robot has no trouble with the traffic situation of road narrowing. However, people do not accept the robot in this setting. The data tell that the acceptance score in this setting is fairly high, which indicates that people value a good performance. The performance of this setting is not good enough to ensure acceptance. Setting 2, where the robot drives through pillars, has an insufficient performance. Due to the obstacles, there is little room to move, which apparently is a difficult situation for the robot. This makes that the robot does not perform well, to such an extent that acceptance is not achieved.

It is interesting to look at the results in relation to each other, instead of only interpreting the results individually. One finding that stands out is that scenario 4 has the lowest performance score and the lowest acceptance score. This means that out of the four scenarios, this scenario has the most favourable results regarding roboreadiness. This result in not surprising, since this is the scenario that contains the bend in the road. There is much free space so that people are not easily hindered, as the robot can manoeuvre around a pedestrian without any problems. Furthermore, the results of the survey indicate that the factor ‘predictability’ is the most important factor in the determination of the social acceptance. It gets the highest average score of all factors in every scenario, and the least variability in the ranking with percentages. It is thus important that the robot behaves in a predictable way. As to be expected, the factor ‘dimensions’ scores the highest, when comparing this factor among the scenarios, in scenario 2. In this scenario, the delivery robot drives along pillars, which makes that the path is narrow and people/robots have to be more considerate of each other. On a narrow path, there is less space to move, so people are more likely to be bothered by the robot. Therefore, the dimensions of the robot play an important role in the degree of hindrance.

Overall, the findings indicate that settings where there is space to pass each other easily, are the most favourable. This combines well with the fact that the predictability of the delivery robot is important, because with more free space on the road a worse predictability might be less applicable.

8.3. Implications

With the development of the assessment method, this research contributes to the theory building in the field of delivery robots. The method can be seen as a start to which improvements can be made, so eventually it may lead to large scale usage. Being able to determine the level of roboreadiness of a traffic environment can support in the future roll-out of delivery robots in the public space.

Since there is not much scientific literature on this topic yet, first steps have to be taken to gain experience and shed light on potential issues. The assessment method provides information about factors that are considered important, and traffic conditions that affect performance. In addition, this research already provides first insights, which are obtained during the validation of the method. Data are collected from the first and only operating delivery robot in the Netherlands. This research is distinctive from other studies, since a real driving delivery robot is used. Other studies like the one by Abrams et al. (2021), use hypothetical situations to obtain data, while this research acquires data of people who had real-life experience with the robot in the settings.

8.4. Limitations

For the validation, the method was performed on a small scale. Different findings might have been found if it had been carried out on a larger scale. The results are therefore initial insights, no firm conclusions can be drawn from this.

The assessment method is limited to active modes traffic environments, this means only locations can be examined that have a low traffic intensity. Hereby difficult traffic situations do not occur. Therefore, this assessment method is not usable for other kind of traffic environments.

Another limitation concerning the validation of the method, is that it is executed in the first pilot with a delivery robot in the Netherlands. This means it is a new appearance, it is likely people have never seen a delivery robot in real-life before. This can give different results regarding acceptance than in a steady state situation, when delivery robots are more common. Other factors might be important further into the future.

9

Conclusion and recommendations

After the desk research and the assessment method development, it is time to come to a conclusion in this last chapter. The answers to all research questions are recapitulated in the first section, leading to a final conclusion. In the second section, recommendations are given for further research and for practice.

9.1. Conclusion

Because it is expected that in the future 80% of the goods deliveries will be made by autonomous vehicles, and because in other countries delivery robots are already in operation, it can be assumed that delivery robots will also be introduced in the Netherlands. In December 2021, a first pilot was realised, where a delivery robot delivers groceries at the campus of the Erasmus University Rotterdam. In this way, experience can be gained and research performed. Before a large scale roll-out of delivery robots can be realised, it is important to study whether society is ready for it. The question is what determines this readiness.

A first round of literature research showed that for the ‘roboreadiness’ (the ability for a delivery robot to operate in the environment), the infrastructure, the techniques and whether people accept the robot are the most important. These three elements: public space, robot and human are the main topics of this research. This is converted into traffic environment, performance and social acceptance, which were explored further. In this way, insights have been gained that could support the way to a successful implementation of delivery robots. No method existed yet, to examine whether the traffic environment is suitable or not. Therefore, this thesis proposed an assessment method.

In order to get there, a literature study was performed first. Factors that play a role in the performance and acceptance of technology innovations were identified. This led to a conceptual model, showing the connections between the elements and presenting the influencing factors. The traffic environment is often a given, which makes the performance and acceptance the dependent elements. The factors determining these latter two, in relation to the traffic environment, are defined as ‘pace’, ‘continuity’, ‘deviation’, ‘safety’, ‘compliance’, and ‘predictability’, ‘competence’, ‘comfort’, ‘dimensions’, respectively. These findings are presented in the conceptual model, shown in Figure 9.1. The performed desk research answered the first sub-question of this research:

“What are the factors that determine the roboreadiness of a traffic environment?”

To determine the roboreadiness of a traffic environment, it is thus important to be able to assess the performance and the social acceptance. Therefore, a methodology is established that can assess the factors involved. In this development, it is important to have the conditions clear first. This marks the first stage of the assessment method development: the set-up. Here, the context, assumptions, and input that is needed, are described. It states what conditions the characteristics of the environment have to meet, to be able to study the roboreadiness of the traffic environment.

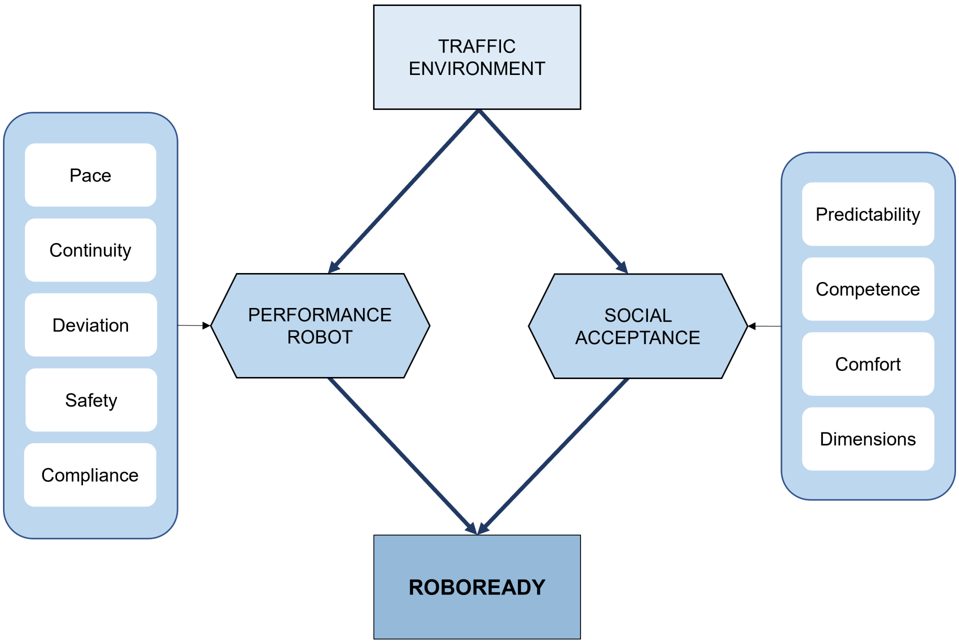


Figure 9.1: Conceptual model of the factors influencing the roboreadiness.

If the research goal meets these descriptions, the next step is to assess the factors. This can be done by means of a test-case and a survey, executed in the specified settings. With the test-case, the performance factors can be assessed by observing the delivery robot while in operation. With the survey, the level of acceptance can be determined by asking people to weigh and score the acceptance factors per scenario. In this way data are collected, which have to be analysed in order to interpret the results. This leads to the level of performance and level of social acceptance of the settings, and thereby provides an answer to the second sub-question:

"What kind of methods can be used to assess these factors?"

After the analysis of the results obtained with the test-case and the survey, the level of performance and social acceptance of the settings are known. These aspects together determine the level of roboreadiness of the traffic environment. Hence, the answers to the two sub-questions lead to the answer to the main research question:

"How can the roboreadiness of a traffic environment be determined?"

All together, it can be concluded that the proposed assessment method can be used to determine the level of roboreadiness of a traffic environment.

9.2. Recommendations

Since delivery robots are a relatively new concept, there is still much to explore. This makes that there are a lot of research opportunities. The research carried out in this thesis fills a small part of the knowledge gaps. Therefore, recommendations are suggested for further research in this section. Additionally recommendations for practice are proposed, to elaborate on the research carried out in this thesis.

9.2.1. Recommendations for further research

The research in this thesis contributes to filling the knowledge gap on integration of delivery robots in public space. Since it covers a small part of this gap, many uncovered aspects on this topic remain. Further research could be performed on the impact of the design of the delivery robot on the social acceptance. Regarding the performance of the robot, the usage perspective can be taken into account. Moreover, the role of the delivery robot in the logistical process could be interesting to investigate.

Furthermore, the scope of the research could be extended to other traffic environments, with other characteristics. In addition, it could be interesting to investigate whether the proposed assessment method could be used for other automated systems.

To proceed on the research of this thesis, the proposed assessment method could be executed. When performing the test-case and the survey on a large scale, as it is supposed to be done, the influence of the traffic environment on the level of performance and on the social acceptance can be defined. If this shows evident relations, conclusions might be drawn on the impact of certain traffic situations on the performance of the robot or on the acceptance by people. This is valuable for the implementation strategies of delivery robots. Furthermore, since the assessment method is just a beginning and improvements are suggested, the method can be further elaborated in future research. This can make the method more accurate and reliable.

9.2.2. Recommendations for practice

The proposed assessment method could be used by companies wanting to implement delivery robots in the public space. By performing the test-case and the survey, the traffic environment can be examined on the roboreadiness. Additionally, by execution of (part of) the method, data can be obtained in different traffic scenarios. This data can be used in future projects, for similar settings.

The execution of the method also provided information about the importance of the factors. In the implementation of delivery robots in future pilots this can be taken into account, by paying extra attention to these aspects.

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A

Scientific paper

Are we roboready?

Developing a method to determine the roboreadiness of a traffic environment

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Abstract

Autonomous delivery robots are a promising alternative for last-mile delivery. To realise successful implementation of delivery robots in the public space, it is important to study the interaction between robot and environment. The traffic environment includes the physical infrastructure, traffic conditions and the people using the environment. This research proposes an assessment method that can be applied to determine the 'roboreadiness' of a traffic environment. This expresses whether the environment is ready for delivery robots to drive there. The performance of new transport concepts and the acceptance of innovations in the transport system are studied in a literature review, leading to the important factors. This is translated into a conceptual model which is the basis for the development of the method. To be able to assess the factors, suitable sub-methods are chosen and elaborated. To study the performance of the robot in its traffic environment a test-case can be performed and to examine the social acceptance a survey can be conducted. Analysing the resulting data leads to the level of roboreadiness. As a final step in the development of the method, a validation is carried out. While demonstrating the assessment method, it follows that the method is suitable for determining the level of performance, social acceptance and consequently the roboreadiness. In addition, first insights regarding the performance and social acceptance of the delivery robot at the campus of the Erasmus University Rotterdam are presented. The proposed assessment method can be used to collect data that can be useful for future projects. Although the method is valid, suggestions for improvements are made for further research.

Key words: delivery robots, robot performance, social acceptance, assessment method, roboreadiness

In the world of today, everything has to be better, faster and more sustainable. There is a search for alternative ways of allowing processes to take place without human intervention. Automated goods delivery is expected to cover 80% of all business to customer deliveries in the future (Joerss et al., 2016). But is society ready for this?

The current trend towards automation and digitisation has big impact on the way products are manufactured and distributed. Technologies enable machines and computers to communicate with each other, allowing decision-making processes to take place without human intervention (Stampa, 2020). By using smart systems based on new technologies, logistical tasks can be automated which improves efficiency and performance (Jagtap et al., 2020). Currently, last-mile logistics are the least efficient step within supply chains and could benefit from automation (Ranieri et al., 2018). Last-mile delivery is facing multiple challenges, requiring technological innovations to keep up with the high demand and the service requirements (Boysen et al., 2020). First of all, due to globalisation and the growth in e-commerce, freight transportation has increased in volume. Another trend that affects last-mile delivery is urbanisation. To handle the demand, delivery vans, scooters and bikes of many different providers are driving around in cities, thereby causing a nuisance. This is not only in terms of congestion, but also in forming obstacles on sidewalks. With the growing attention towards sustainability and new legislation aimed at mitigating climate change, there is a call for environment-friendly alternatives for last-mile delivery (Kiba-Janiak et al., 2021). Furthermore, due to competition, delivery prices are relatively low and delivery speed keeps on increasing. Next-day, or even same-day delivery are becoming the standard. As a consequence, delivery companies have to scale up in a short period of time. This is already leading to a shortage of trained and experienced parcel deliverers (De Buren, 2021). In combination with the fact that the workforce is aging, there is an impending shortage of staff. As a consequence, packages are delayed and customers do not receive their products on time. Alternative delivery concepts that are less dependent on human activity are therefore desirable.

Current literature on the topic of delivery robots shows that automation in last-mile logistics could lead to cost and time reduction and can provide a sustainable way of delivering goods (Lemardelé et al., 2021; Figliozzi and Jennings, 2020; Chen et al., 2021). However, there is a need for more research on the integration of delivery robots in the public space (Li et al., 2021). Since the delivery robot is a relatively new concept, the research area is growing and not yet mature, which could be the reason for the lack of theory. Studies are limited because there are relatively few cases, so not much data is available on the performance of delivery robots. Studies from countries where delivery robots are being used (USA, UK, Germany, Denmark, Estonia), are not directly applicable to the Netherlands because of infrastructural and cultural differences. Before a large scale roll-out of delivery robots can be realised, it is important to know whether implementation could be successful in the environment. Therefore, the interaction between the robot and the environment has to be studied. In this research, the environment consists of the physical infrastructure and its traffic conditions, and of the people in the surroundings who have to deal with the delivery robot.

This paper proposes a methodology that can be applied to determine the 'roboreadiness' of a traffic environment, which expresses whether the environment is ready for delivery robots to drive there. As the robot has to deal with a lot of robot-environment and human-robot interaction, the success of the implementation depends on both: the performance of the robot in the given traffic environment and whether people are prepared to interact with it. The performance and social acceptance are assumed to depend on the traffic environment, since the latter is a given in this research. In order to contribute to the theory building in this research area, an assessment method is proposed. The second section contains a literature review leading towards a conceptual model, defining the key elements for the integration of delivery robots in the public space. In the third section, the three different stages of the assessment method development are explained. The validation of the assessment method includes a demonstration of the method using a pilot with a delivery robot in the Netherlands. The fourth section provides a discussion of the method, including a reflection, the implications and the limitations. To conclude, the fifth section summarises the findings and outlines recommendations for future research.

Towards a conceptual model of influencing factors of roboreadiness

In order to successfully implement delivery robots in public space, it is important that the delivery robot interacts with the environment. In the environment the robot encounters multiple aspects: the physical infrastructure, traffic conditions and people. Since the physical characteristics of the infrastructure are often a given, the delivery robot has to adapt to the present circumstances. It is essential that the traffic environment and the people are ready to deal with the delivery robot when it is implemented (Oztemel et al., 2009). To make sure that the robot can be successfully implemented in a certain area, the relation between the traffic environment and the performance of the robot, as well as the social acceptance, need to be known. The factors influencing the performance and social acceptance are defined in the coming two subsections.

Performance of new transport concepts

The performance of a new technology is an essential indicator for the level of success (Tian et al., 2018). The performance states how the robot performs in the given traffic environment. The challenges of today arise in adapting cities to its current needs (Paiva et al., 2021). Ideally, transport innovations should be functional within the existing environment. On the other hand, when areas change or if they are newly built, the environment can be suitably adapted to the innovation. When integrating new transport concepts into the traffic environment, it is important to study the interaction between the innovation and its surroundings before realising the implementation. Tomitsch and Hoggenmueller (2021) state that it is a challenge to design or implement automated systems in public spaces, because it can be dependent on the physical context, the people involved and their norms. Fisher (n.d.) introduced a set of principles that can provide guidance for designing automated applications in urban areas. These principles include the integrity and quality of the urban realm, enclosure and continuity, ease of movement, accessibility, diversity, legibility and adaptability. The flow of people must not be adversely affected (Tomitsch and Hoggenmueller, 2021). With the implementation of delivery robots in public spaces, it is essential that these principles are not violated. When examining the performance, these aspects are thus important to take into account. Performance factors in case of the delivery robot that are covered by these aspects are continuity, deviation and pace.

Not much is examined yet about the interaction between a delivery robot and its environment. However, the performance in public spaces of other types of robots is investigated, for example by Oztemel et al. (2009). They defined a set of criteria to measure the performance of swarm robots. The criteria belong to five aspects that cover all important indicators for measuring performance. These aspects are feasibility, manageability, usefulness, acceptability and necessity. The first two aspects can be applied to the context of delivery robots within the traffic environment. Feasibility implies that the risks and technology the robot brings, are feasible. Speaking about the performance of the delivery robot, this means the robot must operate safely. The other aspect, manageability, entails functions of the robot that can easily be performed without violating operational rules. For delivery robots this can be interpreted as not violating traffic rules, which gives the factor compliance.

This research focuses on the factors that determine the performance of the delivery robot in relation to its traffic environment. Therefore, the influencing factors are limited to the part when the robot is driving, it does not take into account the performance related to the delivery service (for example the pick- up/drop-off). The factors that determine this performance are listed below:

- Pace
- Continuity
- Deviation
- Safety
- Compliance

Social acceptance of technology innovation

Acceptance is an important aspect for technological innovations implemented in public space. An innovation can succeed or fail based on the social acceptance. Even if the innovation can improve efficiency and is more sustainable than the alternative, it will only be a success if people interact with and accept it (Devine-Wright, 2007). In order to be accepted, the innovation has to meet basic usability requirements and be recognised as useful (Dillon, 2001). Acceptance is a broad term and does not have one single definition. It can also be different for users and non-users of the innovation. This research focuses on the innovation within the traffic environment. Therefore, the social acceptance is studied, which expresses the acceptance by people who interact with the innovation on the streets. This includes non-users, like pedestrians or other road users who do not necessarily choose to use or interact with the delivery robot, but have to coexist with it and are thus involuntarily exposed to the innovation.

Current technology acceptance models focus mainly on the acceptance of the user of the technology. The original and widely used Technology Acceptance Model (TAM) of Davis (1989) presents two factors that, according to him, determine the acceptance: perceived ease of use and perceived usefulness. These factors have a positive correlation with the intention to use the technology. This is thus a usage-related acceptance model. The factors are influenced by aspects like subjective norms, relevance, and attitude toward technology. Many researchers have built upon TAM, in different areas of research. Another well known acceptance model is the Unified Theory of Acceptance and Use of Technology (UTAUT), by Venkatesh et al. (2003). Here, the two factors from TAM are translated to performance expectancy and effort expectancy. In addition, social influence is added in this model. These two models, TAM and UTAUT, are general and can be applied to all sorts of technologies. More specific models, to narrow down to the context of automated systems, are the Automation Acceptance Model (AAM) and the Car Technology Acceptance Model (CTAM). These are created as an expansion of the original models, and include factors like trust, safety, and anxiety (Ghazizadeh et al., 2012; Osswald et al., 2012). In robotics research, acceptance models exist as well and focus on aspects such as appearance and social ability of the robot. One example is the so-called Autonomous Delivery Vehicle Acceptance Model (ADV-AM), which includes the constructs that predict the behavioural intention to use delivery robots. This model is created by Kapser and Abdelrahman (2020), who investigated the acceptance by users of delivery robots in Germany, adapting an extended UTAUT model to the context of last-mile delivery robots.

All models mentioned so far, predict actual system usage and thereby focus on acceptance by the user of the technology. However, in case of the delivery robot, non-users are also important to take into account. Non-users are people being nearby the delivery robot, who do not necessarily have the behavioural intention to use the technology. Therefore, aforementioned models are not directly applicable. However, acceptance can still play an role, to assure a smooth coexistence on the sidewalks. To keep the overview of the different acceptance models, Table 1 shows the models and their belonging factors.

Abrams et al. (2021) explain why the current technology acceptance models are not suitable to apply to delivery robots. Usage-related technology acceptance includes intentional and social interaction, appearance and form, usage, and autonomy. These aspects are not necessarily relevant for non-users, they explain. For that reason, Abrams et al. (2021) introduced a new concept and came up with the term Existence Acceptance (EA). Hereby, the focus is on the acceptance of a technology by non-users. This means passive approval of the presence of the delivery robot. Several factors should be taken into account to determine the existence acceptance. These are defined as the level of competence, interest, discomfort, enjoyment and the general perceived usefulness for society and subjective social norms.

Not many studies exist about the interaction between delivery robots and people. However, research about other automated systems provides some insights. Fraedrich and Lenz (2016) write about acceptance of autonomous driving, whereby results of other studies are analysed and used as input for their own investigation on the view of road users on the technology. In their article, they present a two-level category system, whereby within a certain context, object-related as well as subject-related aspects play a role. This research on delivery robots is limited to the acceptance related to the operational part. Therefore factors like privacy or design are not taken into account. This makes that only the aspects 'perceived features of the technology', and 'evaluative attitudes and expectations' from the two-level category system are applicable to this case. Factors that belong to these aspects are comfort and convenience, and interest, respectively. Comfort and interest correspond with the theory of existence acceptance of Abrams et al. (2021). Another example of human-machine interaction with regard to autonomous driving, is about the acceptance of semi-automated truck platooning. In a study by Castritius et al. (2020), people from Germany and California were asked to fill in an online questionnaire about their attitudes towards the technology and behavioural intention to cooperate with heavy truck platoons. Constructs that can be translated to delivery robots in the public space are expected usefulness of the concept, expected ease of sharing the road, and specifications of the vehicle. Associated factors for delivery robots are general perceived usefulness, predictability and dimensions of the robot, respectively.

Table 1
Acceptance models and associated factors.

Model	Source	Factors
TAM	Davis (1989)	perceived ease of use & perceived usefulness
UTAUT	Venkatesh et al. (2003)	performance expectancy & effort expectancy & social influence
AAM	Ghazizadeh et al. (2012)	compatibility & trust & perceived ease of use & perceived usefulness
CTAM	Osswald et al. (2012)	perceived safety & anxiety & performance expectancy & effort expectancy & social & influence & facilitating conditions & self efficacy & attitude towards using technology
ADV-AM	Kapser and Abdelrahman (2020)	perceived risk & price sensitivity & performance expectancy & effort expectancy & social influence & facilitating conditions & hedonic motivation
EA	Abrams et al. (2021)	competence & discomfort & interest & trust & enjoyment & threat & general perceived usefulness for society & subjective social norms

From the literature about technology acceptance models and human-machine interaction, various factors can be extracted that influence the acceptance of an innovation. This study focuses on the impact of the traffic environment on the social acceptance. Therefore, only factors that can vary per environment are considered, and not the factors that determine the acceptance in general. This leads to the following list of factors:

- Predictability
- Competence
- Comfort
- Dimensions

Conceptual model

In the previous subsections, the factors belonging to the performance and acceptance are explained. These are translated into a conceptual model showing the existing connections between public space, robot and human. The model is illustrated in Figure 1. The elements in the conceptual model form the basis for the development of the assessment method. The factors are the core aspects that are used in the sub-methods.

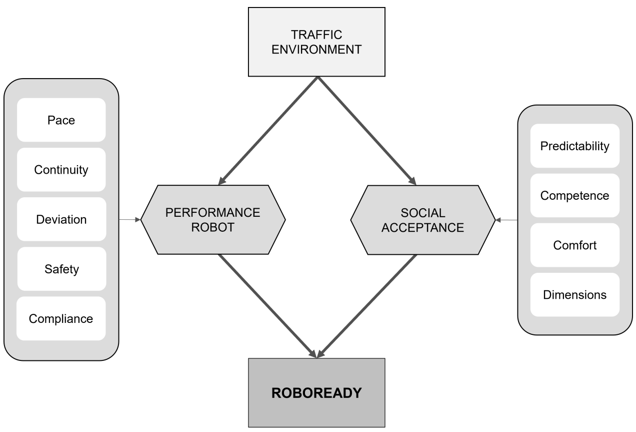


Figure 1. Conceptual model of the factors influencing the roboreadiness.

The traffic environment is given in this research and has an influence on both the performance of the robot as on the social acceptance. In the model, the factors that determine the performance and the social acceptance are listed next to the elements and connected with an arrow. The value of these factors determine the level of performance and the level of social acceptance. Consequently, these determine the state and the level of 'roboreadiness'. This can be interpreted as the society being ready for the delivery robot to be part of the street scene. When the factors have an acceptable value and therefore ensure a sufficient level of the elements, the delivery robot can be successfully integrated in the public space.

Assessment method development

The aim of the assessment method is to be able to determine if a traffic environment is roboready. To verify this, the performance and the social acceptance have to be known. This can be realised by examining the two aspects in the present traffic situations of the traffic environment. The factors that are assessed are based on the conceptual model. The assessment method development consists of three stages. First, the context of the study and the requirements for executing the method are defined during the set-up stage. Second, the assessment method itself is described. The steps that must be carried out if someone wants to investigate whether a traffic environment is suitable for a delivery robot are stated. This includes specifying the traffic environment, two sub-methods to obtain data on the performance and the social acceptance, and the analysis of the data to come to a conclusion. Third, the assessment method is validated, to check whether the method does what it is supposed to do.

Set-up

The context of the study includes an autonomous sidewalk delivery robot in the traffic environment, which consists of two aspects: the physical infrastructure and the traffic conditions. Table 2 gives an overview of the

Table 2
Factors of the traffic environment.

Factor	Explanation
Infrastructure	
Width	Wide or narrow (>= or < 2 metres alongside the robot)
Alignment	Curves or straight path
Crossings	Paths from other directions: yes/no
Elevations	Flat or change in elevation
Traffic conditions	
Other road users	Pedestrians and/or cyclists
Intensity	Amount of traffic: # of people in $r = 5m$ around the robot
Density	Amount of free space: free m^2 in $r = 5m$ around the robot
Visibility	Field of vision: % of the view that the robot can see
Speed	Speed of the other traffic participants in km/h

factors of the type of traffic environment considered, divided into the two aspects. The factors are chosen based on the pilot taking place at the campus of the Erasmus University Rotterdam, since this traffic environment is used for validation of the method. It includes the most common factors of traffic environments.

The assessment method can be used if the goal of the research is in the scope of the description, and if all the conditions are met. The assumptions and pre-conditions are listed below.

Assumptions

- The traffic environment is a given and does not change.
- There are no extreme weather conditions at the time of execution.
- The delivery robot functions properly under normal circumstances.

Pre-conditions

- The delivery robot has to be driving autonomously, and not manually operated.
- The traffic environment has to be an active modes traffic environment.
- There are no other factors present in the traffic environment than the ones listed in Table 2. Combinations of the factors can be included.
- The traffic environment must contain the traffic conditions listed in Table 2, and no other characteristics than that.

To assess the performance and the social acceptance, indicators of the factors are defined. The factors are monitored during the execution of the method, and evaluated based on the value of the indicator. The indicators belonging to the factors of the performance and the social acceptance are presented in Table 3 and Table 4, respectively.

Table 3
Indicators of the performance factors.

Factor	Indicator
Pace	Number of times speed of robot differs with other traffic participants
Continuity	Number of unnecessary stops
Deviation	Number of times robot unnecessarily deviates from the path
Safety	Number of collisions
Compliance	Number of violated traffic rules

Table 4
Indicators of the social acceptance factors.

Factor	Indicator
Predictability	Difference in expected and actual behaviour of the robot
Competence	Functioning of the robot
Comfort	Non-annoyance caused by the robot
Dimensions	Size of the robot

Assessment method

The factors in the conceptual model underlie the choice of the sub-methods used. The assessment method can be used by researchers who want to determine the level of roboreadiness of a traffic environment and agree with the description from the set-up stage. The researcher should follow the steps described in the boxes (* indicates that the step is optional and not required). For a detailed description of the method, the thesis for which this research was conducted is available on request.

Settings
The first step in the assessment method is to divide the traffic environment into traffic situations. Settings have to be created, in which the performance and social acceptance are to be assessed.

Steps to design the settings:
o List traffic situations present in traffic environment
o Define settings by combining factors of infrastructure with most indicative traffic conditions
o Formulate hypotheses about settings/traffic environment

Test-case
The indicators of the factors of the performance can be assessed by means of a test-case. By executing the actions, factors can be assessed and data obtained which can be used to determine the performance of the robot in the desired traffic environment.

Steps to perform the test-case:
o Create the settings in real-life
o Create scenarios: let robot drive through settings
o Assess the indicators per scenario:
- Count # of times pace of robot varies from pace other road users, unplanned stops, unnecessary deviations from straight path, collisions and violations of traffic rules
o Run the test-case 50 times

Survey
By questioning people who are walking in the same traffic environment as the delivery robot, values can be attached to the indicators determining the social acceptance. For this scoring a Likert scale is used, since it is a well-known and reliable way of determining attitudes and perspectives (McLeod, 2019). For the analysis of the data, the multi-criteria analysis is used. With the survey, data can be collected with which the level of social acceptance in different settings can be determined. The template of the survey can be found in the thesis.

Steps to conduct the survey:
o Finalise the survey:
- Choose image for in header *
- Specify introduction text *
- Fill in expected duration survey (depends on # of scenarios)
- Copy p.3 of template as many times as scenarios
- Describe each scenario (supported by images or videos *)
o Distribute survey among a representative group
o Collect responses of at least 20% of people in area

Analysis
After obtaining the data from the test-case and the survey, it is time to analyse the results. With the analysis, the level of performance and the social acceptance can be determined, which together lead to the level of roboreadiness of the traffic environment.

Performance
The data obtained by performing the test-case need to be analysed in order to determine the level of performance of the settings. Table 5 can be used to translate the performance score into the performance level.

Table 5
Levels of performance.

Performance level	Performance score
Good	0 - 25
Sufficient	26 - 50
Insufficient	51 - 75
Bad	76 - 100

Steps to analyse the performance:
o Summarise data per scenario (descriptive statistics):
- Calculate sum, mean, std. dev., var. for all factors
o Perform one-sample t-test to determine whether the mean is significantly different from 0
o Interpret the results
o Check if the data meet minimum requirements:
- Safety = 0
- Pace, continuity, deviation, compliance <= 25
o Translate scores to level of performance:
- Take the sum of the values per factor
- Multiply score of compliance by 10
- Check the level belonging to performance score for each scenario
o Check the hypothesis *

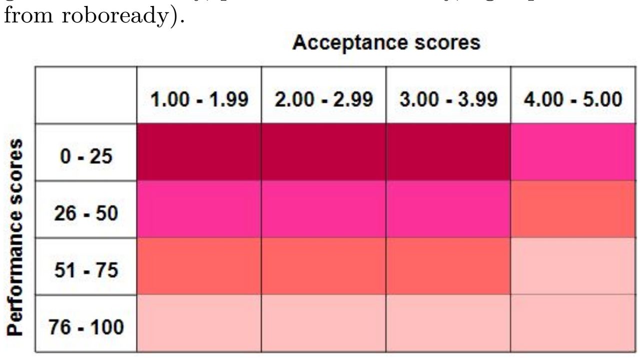
Social acceptance
The data collected by conducting the survey need to be analysed in order to determine the level of social acceptance of the settings. Table 6 can be used to check whether the acceptance score in combination with the performance score leads to social acceptance.

Table 6
The acceptance scores linked to the performance scores (green = acceptance, red = no acceptance).

Steps to analyse the social acceptance:
o Summarise results per scenario:
- Multiply weight of each factor by score of that factor per scenario, per respondent
- Add up multiplications of factors
- Calculate average score per scenario
o Calculate variance of weighted scores of respondents per factor within a scenario
o Interpret the results
o Translate scores to level of social acceptance
o Check the hypothesis *

Roboreadiness
The level of performance and the level of social acceptance together, determine the level of roboreadiness of the traffic environment. For the traffic environment to be roboready, all settings must achieve a sufficient performance and social acceptance. It is assumed that the performance and acceptance scores have the same weight, so the aspects both count for 50%. Table 7 shows the different levels of roboreadiness.

Table 7
The levels of roboreadiness (purple = very roboready, magenta = roboready, pink = not roboready, light pink = far from roboready).



Steps to analyse the roboreadiness:
o Check per scenario if performance score is at most 50 and if social acceptance is achieved
o Translate scores to level of roboreadiness:
(i) If requirements are met:
- Check colour of box of combination of acceptance score and performance score per scenario
- Determine level of roboreadiness of traffic environment by taking average of sum of levels per scenario
(ii) If requirements are not met:
- Check colour of box of combination of acceptance score and performance score per scenario
- Determine level of non-roboreadiness of traffic environment by taking average of sum of levels per scenario (maximum level = not roboready)
o Check the hypothesis *

Validation

The assessment method is executed on a small scale to serve as a demonstration and to validate the method. All actions are followed, leading to a statement about the validity of the assessment method. Furthermore, data is collected which gives a first impression of the robot's functioning in the traffic environment at the campus of the Erasmus University Rotterdam. Performing the validation led to suggestions for improvement, elaborated in the next section. These are not implemented to the method, due to limited time but serve as recommendation for further research.

The four settings present at the traffic environment are: basis, pillars, road narrowing and bend. The hypothesis formulated in this validation is: "The traffic environment at the campus of the Erasmus University Rotterdam is roboready." Data are obtained by performing the test-case and conducting the survey according to the steps of the assessment method. Analysing the results leads to the following performance and acceptance scores:

1. Basis: Perf score = 50, Acc score = 3.92
2. Pillars: Perf score = 60, Acc score = 3.95
3. Road narrowing: Perf score = 40, Acc score = 4.12
4. Bend: Perf score = 20, Acc score = 3.71

Translating these scores leads to the following level of performance and level of social acceptance:

1. **Sufficient** level of perf / Social acc **achieved**
2. **Insufficient** level of perf / Social acc **not achieved**
3. **Sufficient** level of perf / Social acc **not achieved**
4. **Good** level of perf / Social acc **achieved**

To achieve roboreadiness, the performance and acceptance both have to reach a minimal level. The performance must not have a score of more than 50, to have a sufficient level of performance. Setting 2 does not meet this requirement, since it has a performance score of 60 meaning an insufficient level of performance. Moreover, social acceptance has to be achieved in all settings. In setting 2 and 3 this is not the case. The performance is too bad to achieved social acceptance. Since the requirements are not met in all settings, it can be stated that based on the results of the assessment method, the traffic environment is **not roboready**. Therefore, the hypothesis in this validation research: "The traffic environment at the campus of the Erasmus University Rotterdam is roboready." can not be accepted.

With the test-case the performance is assessed, and by means of the survey the social acceptance is determined. These outcomes together made it possible to state the level of roboreadiness of the traffic environment. This is in line with the objectives, and therefore the assessment method is valid.

Discussion

From the validation a number of things emerges that could improve the assessment method. The main point of improvement is using data from the robot instead of obtaining data by means of observations. Implementing the method would take a lot less time. Furthermore, in the determination of the level of roboreadiness, the level of performance and the level of social acceptance have the same weight. However, it could be the case that one of them is more important and should have a higher weight than 50%.

The results obtained in the validation of the method can serve as first insights regarding the delivery robot in the traffic environment at the the campus of the Erasmus University Rotterdam. Overall, the findings indicate that settings where there is space to pass each other easily, are the most favourable. This combines well with the fact that the predictability of the delivery robot seems important, because with more free space on the road a worse predictability might be less applicable.

With the development of the assessment method, this research contributes to the theory building in the field of delivery robots. The method can be seen as a start to which improvements can be made. Being able to determine the level of roboreadiness of a traffic environment can support in the future roll-out of delivery robots in the public space. However, the research knows some limitations. First of all, the scope of the research is limited. The assessment method is only meant for active modes environments, and no difficult traffic situations are taken into account. Therefore, the method can only be representative for similar traffic environments as the campus of the Erasmus University Rotterdam. Furthermore, the validation of the method was performed in the first pilot with delivery robots in the Netherlands. This makes that (the results of) the survey may not be representative for future projects. People may assess their acceptance differently when delivery robots are more common.

Conclusion and recommendations

In this paper, an assessment method is proposed that can be used to determine the roboreadiness of a traffic environment. Therefore, it is important to be able to assess the performance and the social acceptance. A methodology is established that can assess the factors involved. In this development, it is important to have the conditions clear first. This marks the first stage of the assessment method development: the set-up. Here, the context, assumptions, and input that is needed, are described. It states what conditions the characteristics of the environment have to meet, to be able to study the roboreadiness of the traffic environment. If the research goal meets these descriptions, the next step is to assess the factors. This can be done by means of a test-case and a survey, executed in the specified settings. With the test-case, the performance factors can be assessed by observing the delivery robot while in operation. With the survey, the level of acceptance can be determined by asking people to weigh and score the acceptance factors per scenario. In this way data are collected, which have to be analysed in order to interpret the results. After the analysis of the results obtained with the test-case and the survey, the level of performance and social acceptance of the settings are known. These aspects together determine the level of roboreadiness of the traffic environment.

Since delivery robots are a relatively new concept, there is still much to explore. This makes that there are a lot of research opportunities. The research carried out in this paper fills a small part of the knowledge gaps. The proposed assessment method is a step in the right direction. Further research could proceed on this, by making improvements to the method. This can make the results more accurate and reliable. Moreover, the proposed assessment method could be executed in the right way, on large scale. Then, the influence of the traffic environment on the level of performance and social acceptance can be determined. If this shows evident relations, conclusions might be drawn on the impact of certain traffic situations on the performance of the robot or the acceptance by people. This is valuable for the implementation strategies regarding delivery robots. Then it can be said which traffic situations are suitable for delivery robots, without realising a pilot.

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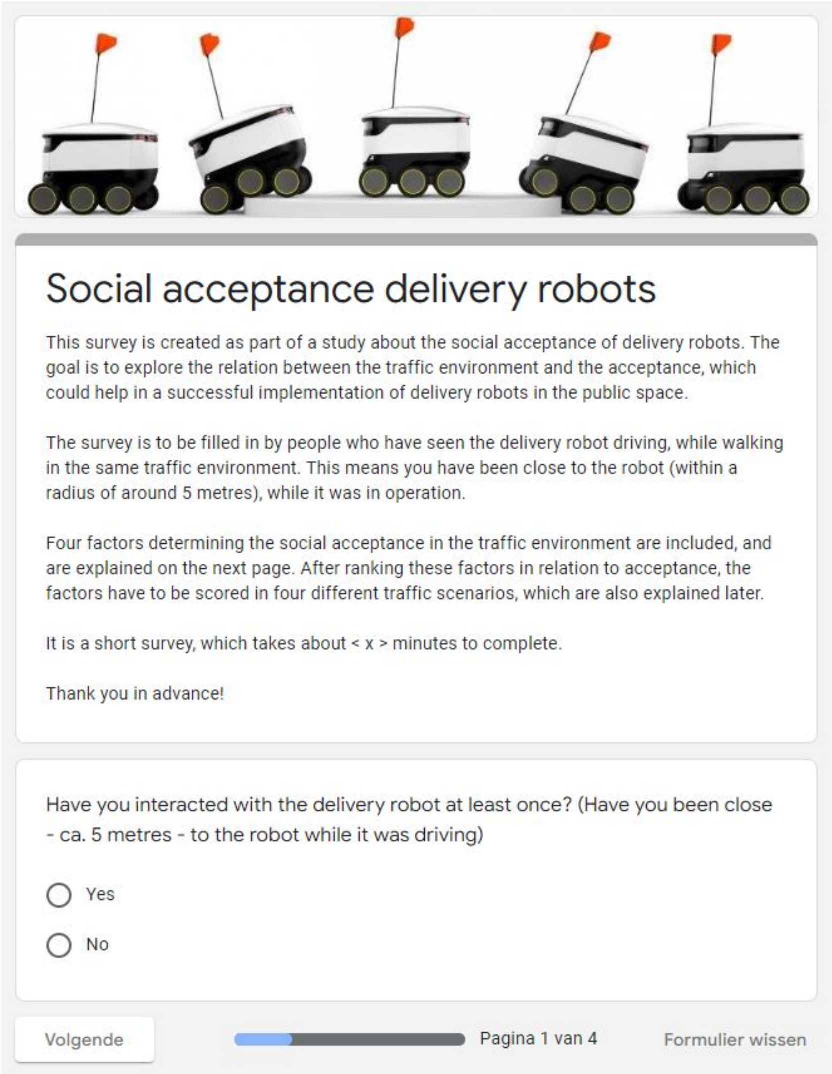
B

Explanation MCA

The multi-criteria analysis (MCA) is a method to make a rational choice based on multiple criteria. Weights and scores are attached to the criteria in various options, to be able to make a decision. The steps to take when using a MCA, applied to this research, are explained below. This is based on the multi-criteria analysis manual by Dodgson, Spackman, Pearman, and Phillips (2009).

1. **Describe the context.**
   Before carrying out the MCA, the decision context has to be described. The decision makers are the people who have had experience with the delivery robot, as in seeing the robot in operation at the campus. The aim of the MCA is to decide the importance of the acceptance factors in the determination of the social acceptance and in different traffic scenarios.
2. **Identify the options.**
   The options considered in the MCA have to be identified. The options are the different traffic scenarios. For each scenario it is to be determined whether social acceptance is achieved.
3. **Define the criteria.**
   The criteria that are in line with the objective, have to be defined. The aim is to determine the level of social acceptance, so the factors influencing this have to be known. This is explored during desk research and resulted in four factors: predictability, competence, comfort and dimensions. For these factors, indicators are specified to make the factors measurable.
4. **Weigh the criteria.**
   The different criteria might not be equally important. Therefore, weights have to be given to the criteria. Percentages are to be given to the factors, reflecting their share in the social acceptance.
5. **Score the criteria per option.**
   The criteria have to be scored for the different options. This means scores have to be given to the factors, in the different traffic scenarios. All the factors have to be scored on a 5-point Likert scale. Hereby, 1 means that the factor is not important at all in the specific traffic scenario, and 5 means that the factor is very important in that specific traffic scenario.
6. **Calculate the weighted averages.**
   To come to a decision, the weighted average has to be calculated for every option. For all factors, the weight and score have to be multiplied, and these have to be summed up, to come to one overall score per option. This score decides whether or not social acceptance is achieved.

C
Template survey



Social acceptance delivery robots

This survey is created as part of a study about the social acceptance of delivery robots. The goal is to explore the relation between the traffic environment and the acceptance, which could help in a successful implementation of delivery robots in the public space.

The survey is to be filled in by people who have seen the delivery robot driving, while walking in the same traffic environment. This means you have been close to the robot (within a radius of around 5 metres), while it was in operation.

Four factors determining the social acceptance in the traffic environment are included, and are explained on the next page. After ranking these factors in relation to acceptance, the factors have to be scored in four different traffic scenarios, which are also explained later.

It is a short survey, which takes about < x > minutes to complete.

Thank you in advance!

Have you interacted with the delivery robot at least once? (Have you been close - ca. 5 metres - to the robot while it was driving)

- Yes
- No

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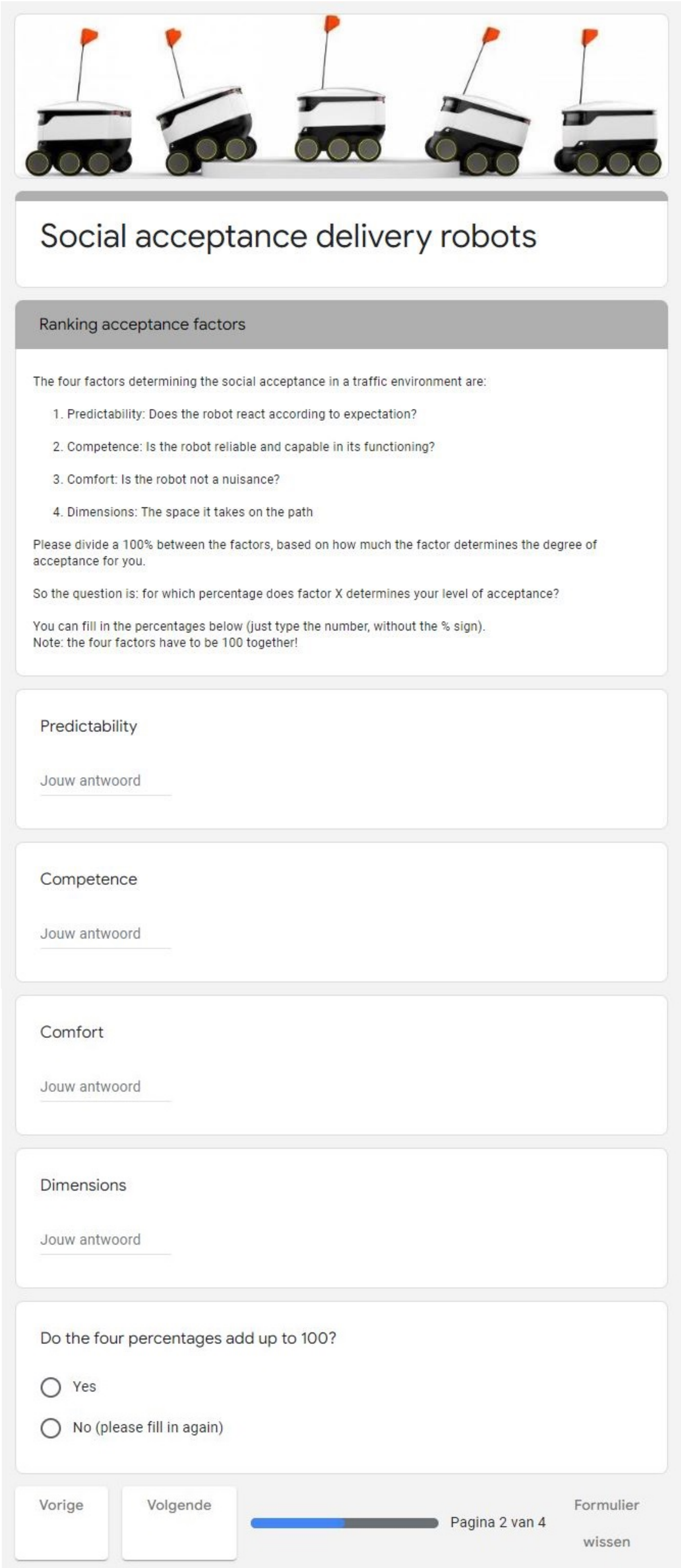
Figure C.1: Survey template page 1.



Social acceptance delivery robots

Ranking acceptance factors

The four factors determining the social acceptance in a traffic environment are:

1. Predictability: Does the robot react according to expectation?
2. Competence: Is the robot reliable and capable in its functioning?
3. Comfort: Is the robot not a nuisance?
4. Dimensions: The space it takes on the path

Please divide a 100% between the factors, based on how much the factor determines the degree of acceptance for you.

So the question is: for which percentage does factor X determines your level of acceptance?

You can fill in the percentages below (just type the number, without the % sign).
Note: the four factors have to be 100 together!

Predictability

Jouw antwoord

Competence

Jouw antwoord

Comfort

Jouw antwoord

Dimensions

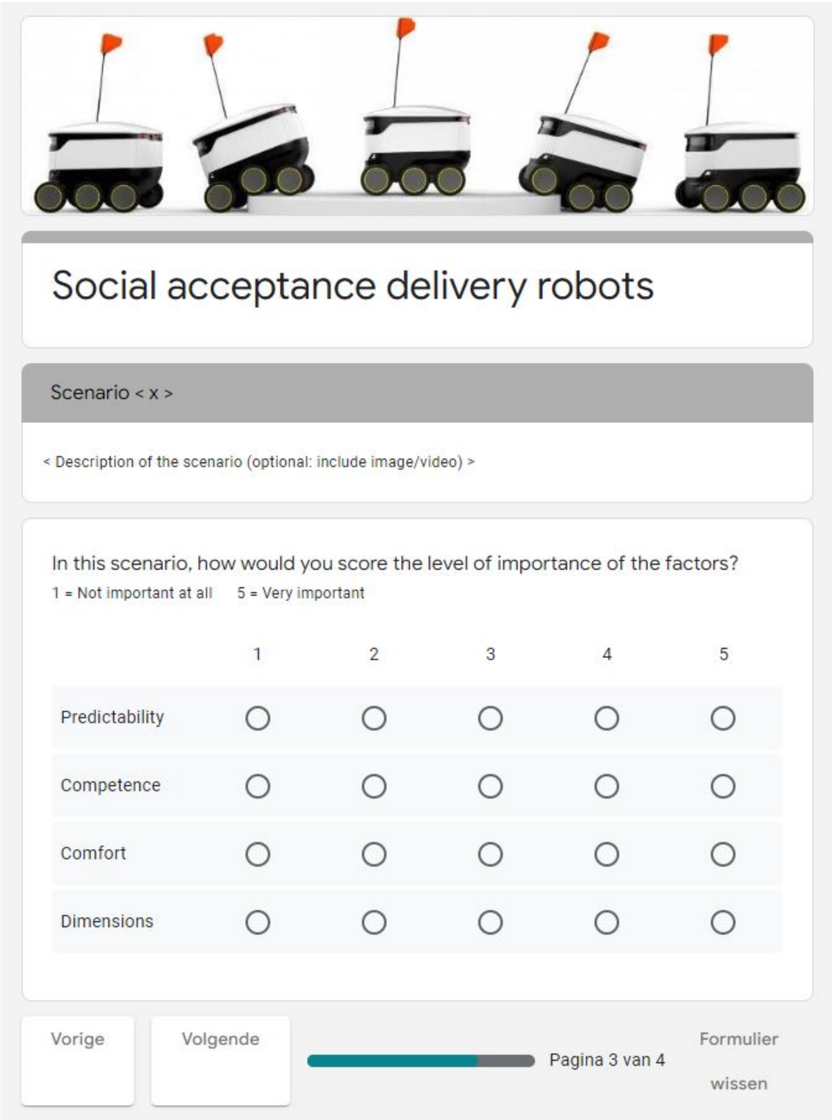
Jouw antwoord

Do the four percentages add up to 100?

- Yes
- No (please fill in again)

Vorige | Volgende | Pagina 2 van 4 | Formulier wissen

Figure C.2: Survey template page 2.



Social acceptance delivery robots

Scenario < x >

< Description of the scenario (optional: include image/video) >

In this scenario, how would you score the level of importance of the factors?
1 = Not important at all 5 = Very important

	1	2	3	4	5
Predictability					
Competence					
Comfort					
Dimensions					

Vorige Volgende Pagina 3 van 4 Formulier wissen

Figure C.3: Survey template page 3.

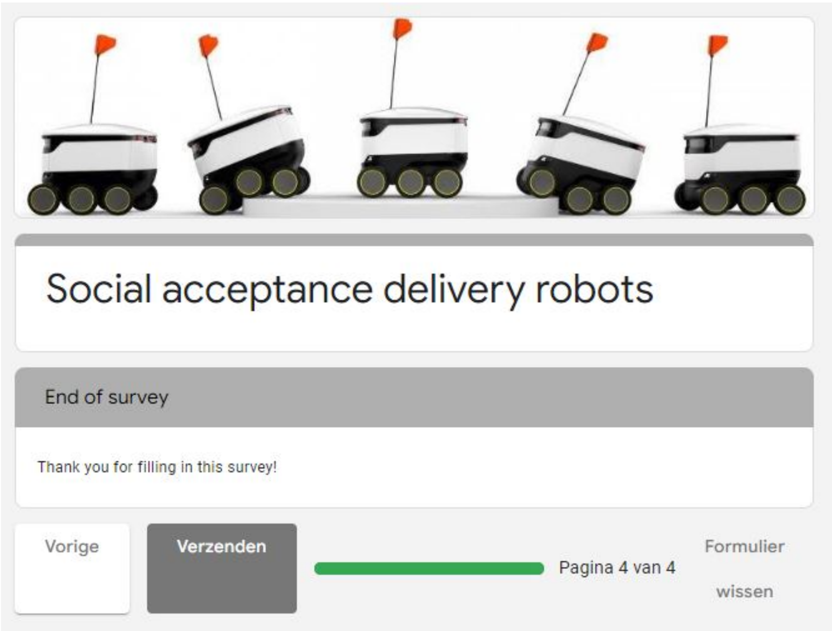


Figure C.4: Survey template page 4.

D
Roboreadiness test

PREPARATION

✓ Check whether all aspect below apply to the to be performed research, if so continue with the roboreadiness test

- ◯ The goal of the research is to determine the roboreadiness of the traffic environment
- ◯ The delivery robot drives autonomously, and is not manually operated
- ◯ The traffic environment is an active modes traffic environment
- ◯ There are no other infrastructure factors present in the traffic environment than:
  - width, alignment, crossings, elevations
- ◯ There are no other traffic conditions present traffic environment than:
  - other road users, intensity, density, visibility, speed

ROBOREADINESS TEST

1 DESIGN SETTINGS

- List the traffic situations that are present in the traffic environment
- Define settings by combining factors of the infrastructure with the most indicative traffic conditions
- Fill in the characteristics in the table

Factor / Setting	Setting 1	Setting ...	Setting ...	Setting n
Infrastructure				
Width	x	x	x	x
Alignment	x	x	x	x
Crossings	x	x	x	x
Elevations	x	x	x	x
Traffic conditions				
Other road users	x	x	x	x
Intensity	x	x	x	x
Density	x	x	x	x
Visibility	x	x	x	x
Speed	x	x	x	x

- Formulate hypotheses about the settings/traffic environment

2 PERFORM TEST-CASE

- Create the settings in real-life
- Create scenarios by letting the robot drive through the settings
- Assess the indicators per scenario, fill in the assessment matrix:
  - Count the number of times the pace of the robot varies from the pace of the other road users, unplanned stops, unnecessary deviations from the straight path, collisions and violations of traffic rules

Scenario < x >

Factor / Iteration	1	..	..	..	n
Pace	x	x	x	x	x
Continuity	x	x	x	x	x
Deviation	x	x	x	x	x
Safety	x	x	x	x	x
Compliance	x	x	x	x	x

- Run the test-case 50 times (n=50)

* optional, not required

3

CONDUCT SURVEY

- Finalise the survey:
  - Choose an image for in the header *
  - Specify the introduction text *
  - Fill in the expected duration of the survey (depends on the number of scenarios)
  - Copy page 3 of the template as many times as scenarios in the research
  - Describe each scenario (supported by images or videos *)
- Distribute the survey among a representative group
- Collect responses of at least 20% of the people in the area

4

ANALYSE RESULTS

Analyse performance

- Summarise the data per scenario using descriptive statistics:
  - Calculate the sum, mean, standard deviation, variance for all factors
- Perform a one-sample t-test to determine whether the mean is significantly different from 0, by using the formula: $t = \frac{\overline{x} - \mu}{\hat{\sigma}/\sqrt{n}}$
- Fill in the values in the table

Scenario < x >					
	Sum	Mean	SD	VAR	p-value
Pace	x	x	x	x	x
Continuity	x	x	x	x	x
Deviation	x	x	x	x	x
Safety	x	x	x	x	x
Compliance	x	x	x	x	x

- Interpret the results
- Check if the data meet the minimum requirements
  - Safety = 0
  - Pace, continuity, deviation, compliance <= 25
- Translate the scores to the level of performance:
  - Take the sum of the values per factor (=performance score)
  - Multiply the score of compliance by 10
  - Check the level belonging to the performance score for each scenario

Performance level	Performance score
Good	0 - 25
Sufficient	26 - 50
Insufficient	51 - 75
Bad	76 - 100

- Check the hypothesis *

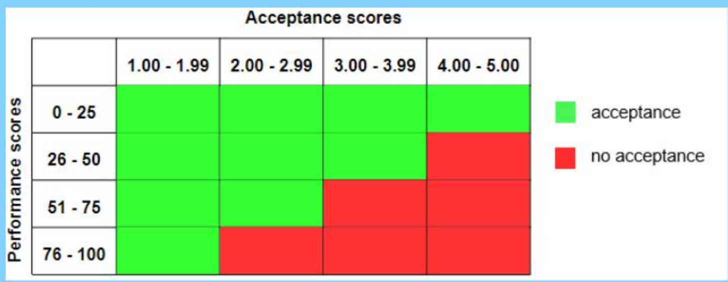
Analyse social acceptance

- Summarise the results per scenario, fill in the table:
  - Multiply the weight of each factor by the score of that factor per scenario, per respondent
  - Add up the multiplications of the factors
  - Calculate the average score per scenario

* optional, not required

	Scenario 1	Scenario ..	Scenario ..	Scenario n
Resp 1	x	x	x	x
Resp ..	x	x	x	x
Resp ..	x	x	x	x
Resp ..	x	x	x	x
Resp n	x	x	x	x
Average	*x*	*x*	*x*	*x*

- Calculate the variance of the weighted scores of the respondents per factor within a scenario
- Interpret the results
- Translate the scores to the level of social acceptance using the table below, by relating the acceptance score to the performance score, per scenario



- Check the hypothesis *

Analyse roboreadiness

- Check per scenario if the performance score is at most 50 and if social acceptance is achieved
- Translate the scores to the level of roboreadiness (see table below):

  (i) If the requirements are met:
    - Check the colour of the box of the combination of the acceptance score and the performance score per scenario
    - Determine the level of roboreadiness of the traffic environment by taking the average of the sum of the levels per scenario

  (ii) If the requirements are not met:
    - Check the colour of the box of the combination of the acceptance score and the performance score per scenario
    - Determine the level of non-roboreadiness of the traffic environment by taking the average of the sum of the levels per scenario (maximum level = not roboready)

- Check the hypothesis *

* optional, not required

E

Pictures of the settings

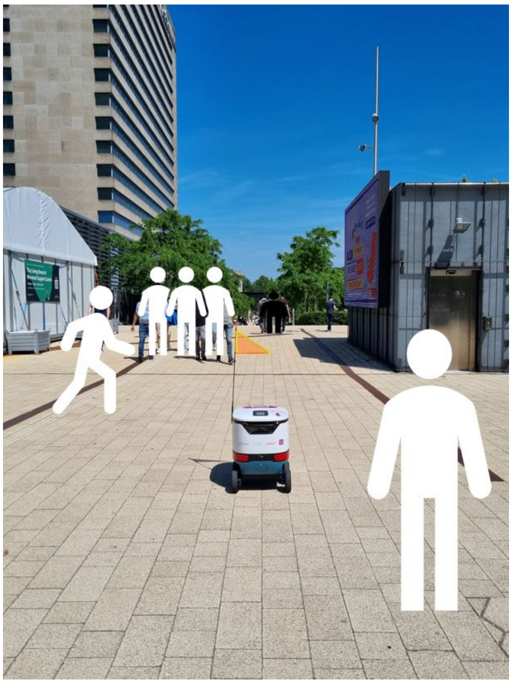


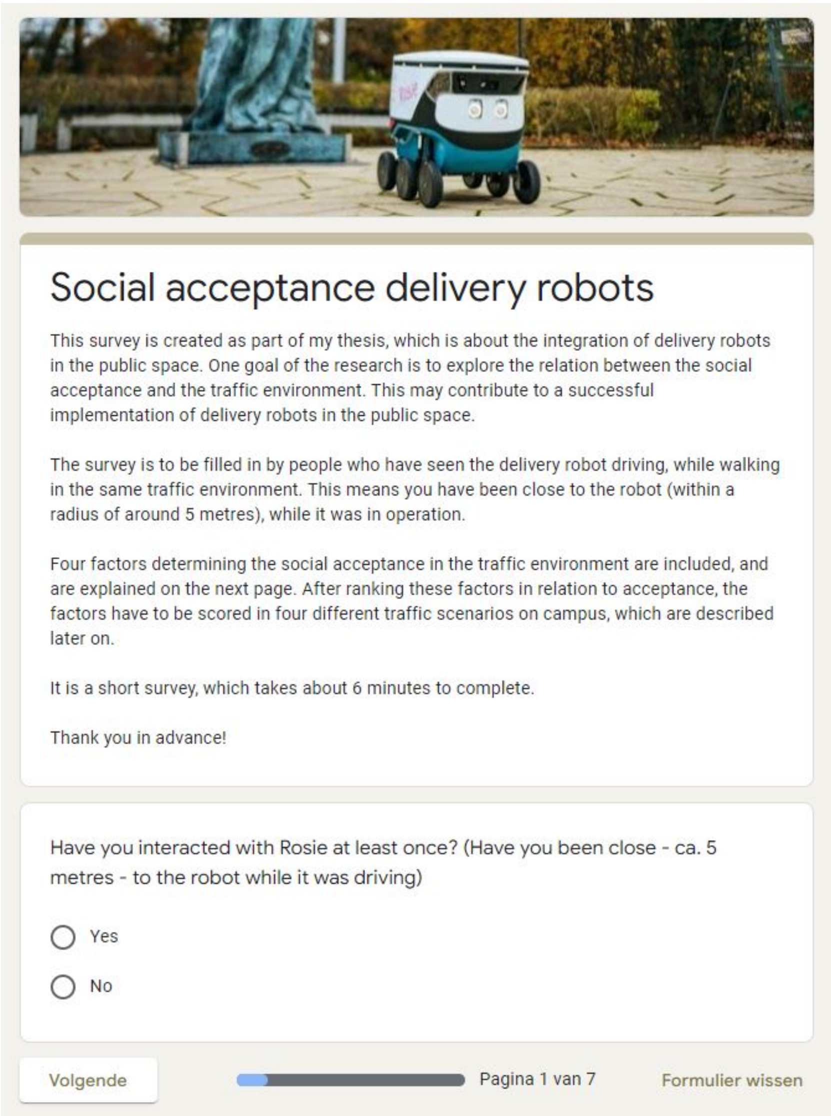
Figure E.1: Setting 1: Basis.

Figure E.2: Setting 2: Pillars.

Figure E.3: Setting 3: Road narrowing.

Figure E.4: Setting 4: Bend.

F
Survey for the campus environment



Social acceptance delivery robots

This survey is created as part of my thesis, which is about the integration of delivery robots in the public space. One goal of the research is to explore the relation between the social acceptance and the traffic environment. This may contribute to a successful implementation of delivery robots in the public space.

The survey is to be filled in by people who have seen the delivery robot driving, while walking in the same traffic environment. This means you have been close to the robot (within a radius of around 5 metres), while it was in operation.

Four factors determining the social acceptance in the traffic environment are included, and are explained on the next page. After ranking these factors in relation to acceptance, the factors have to be scored in four different traffic scenarios on campus, which are described later on.

It is a short survey, which takes about 6 minutes to complete.

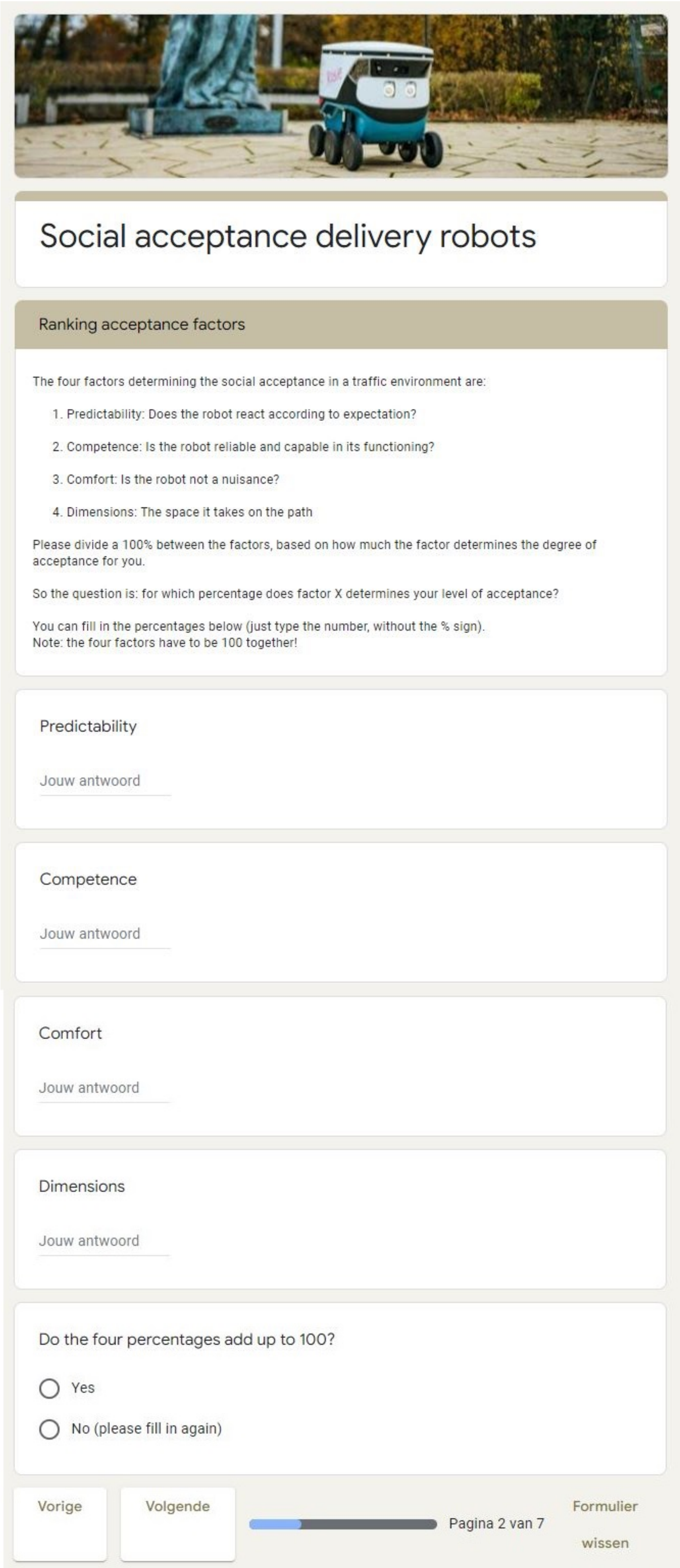
Thank you in advance!

Have you interacted with Rosie at least once? (Have you been close - ca. 5 metres - to the robot while it was driving)

- Yes
- No

Volgende   Pagina 1 van 7   Formulier wissen

Figure F.1: Survey page 1.



Social acceptance delivery robots

Ranking acceptance factors

The four factors determining the social acceptance in a traffic environment are:

1. Predictability: Does the robot react according to expectation?
2. Competence: Is the robot reliable and capable in its functioning?
3. Comfort: Is the robot not a nuisance?
4. Dimensions: The space it takes on the path

Please divide a 100% between the factors, based on how much the factor determines the degree of acceptance for you.

So the question is: for which percentage does factor X determines your level of acceptance?

You can fill in the percentages below (just type the number, without the % sign).
Note: the four factors have to be 100 together!

Predictability

Jouw antwoord

Competence

Jouw antwoord

Comfort

Jouw antwoord

Dimensions

Jouw antwoord

Do the four percentages add up to 100?

- Yes
- No (please fill in again)

Vorige Volgende Pagina 2 van 7 Formulier wissen

Figure F.2: Survey page 2.

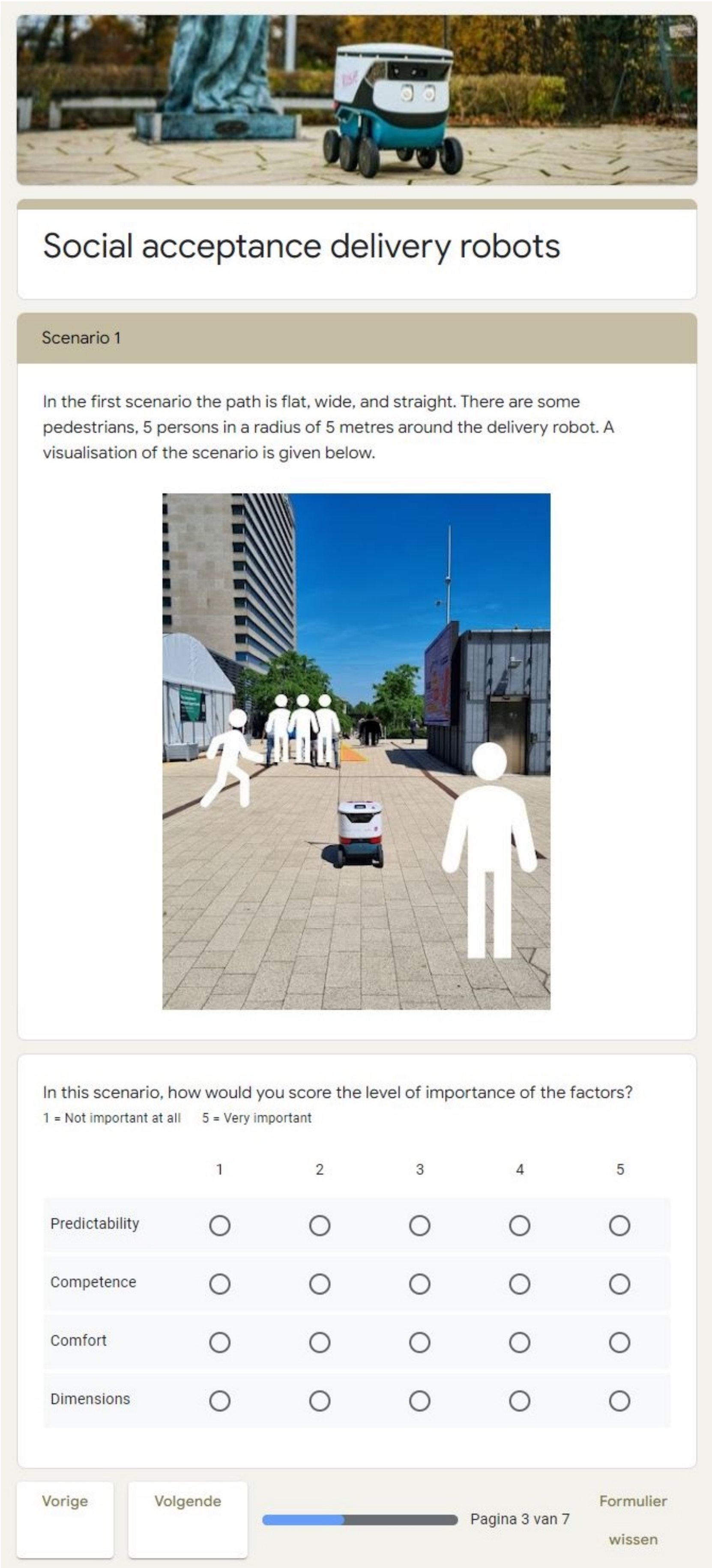
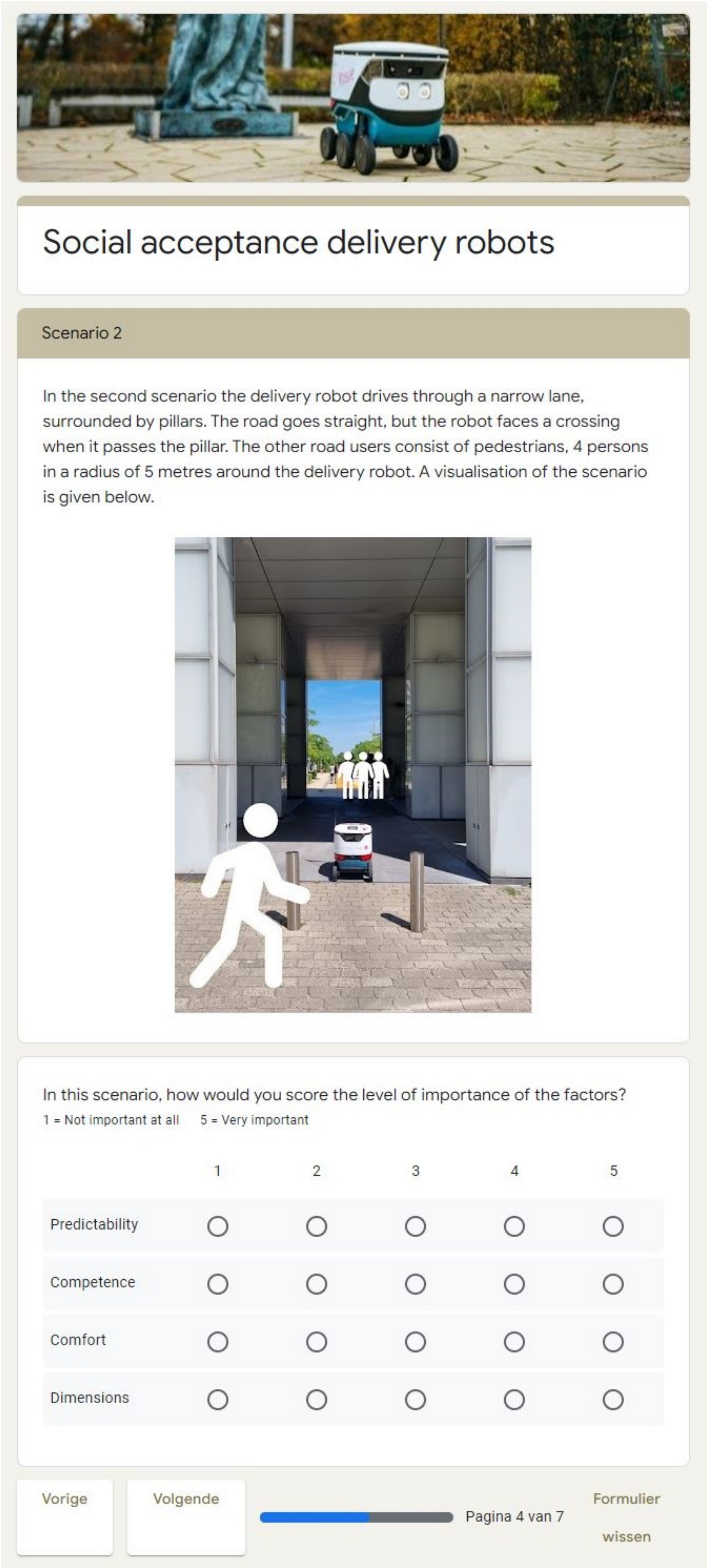


Figure F.3: Survey page 3.



Social acceptance delivery robots

Scenario 2

In the second scenario the delivery robot drives through a narrow lane, surrounded by pillars. The road goes straight, but the robot faces a crossing when it passes the pillar. The other road users consist of pedestrians, 4 persons in a radius of 5 metres around the delivery robot. A visualisation of the scenario is given below.

In this scenario, how would you score the level of importance of the factors?

1 = Not important at all 5 = Very important

	1	2	3	4	5
Predictability	○	○	○	○	○
Competence	○	○	○	○	○
Comfort	○	○	○	○	○
Dimensions	○	○	○	○	○

Vorige Volgende Pagina 4 van 7 Formulier wissen

Figure F.4: Survey page 4.

Social acceptance delivery robots

Scenario 3

In the third scenario the delivery robot encounters a road narrowing and the road goes downhill. Again the delivery robot encounters pedestrians, 5 persons in a radius of 5 metres. A visualisation of the scenario is given below.

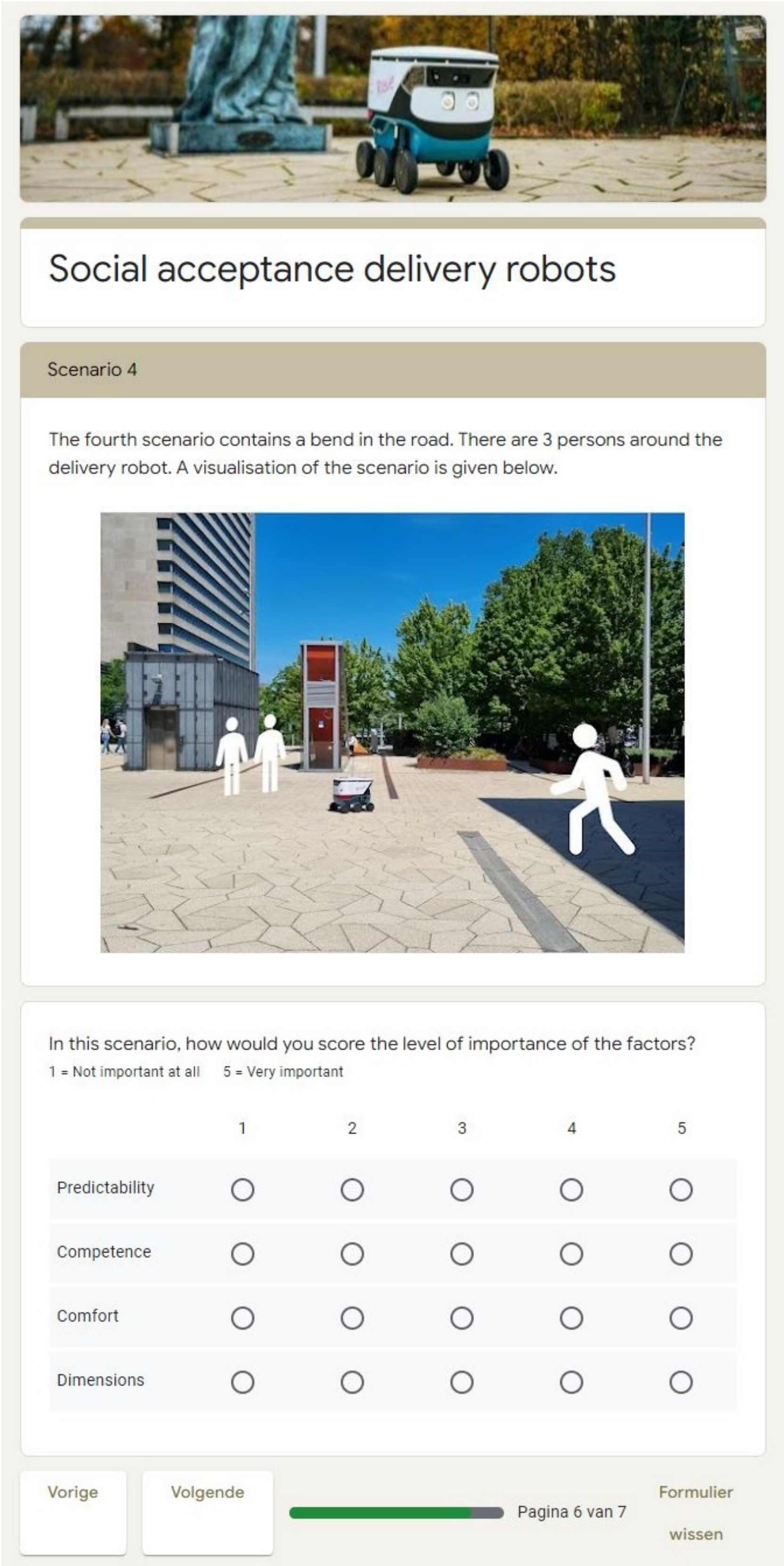
In this scenario, how would you score the level of importance of the factors?

1 = Not important at all 5 = Very important

	1	2	3	4	5
Predictability	○	○	○	○	○
Competence	○	○	○	○	○
Comfort	○	○	○	○	○
Dimensions	○	○	○	○	○

Vorige Volgende Pagina 5 van 7 Formulier wissen

Figure F.5: Survey page 5.



Social acceptance delivery robots

Scenario 4

The fourth scenario contains a bend in the road. There are 3 persons around the delivery robot. A visualisation of the scenario is given below.

In this scenario, how would you score the level of importance of the factors?
1 = Not important at all 5 = Very important

	1	2	3	4	5
Predictability	○	○	○	○	○
Competence	○	○	○	○	○
Comfort	○	○	○	○	○
Dimensions	○	○	○	○	○

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Figure F.6: Survey page 6.

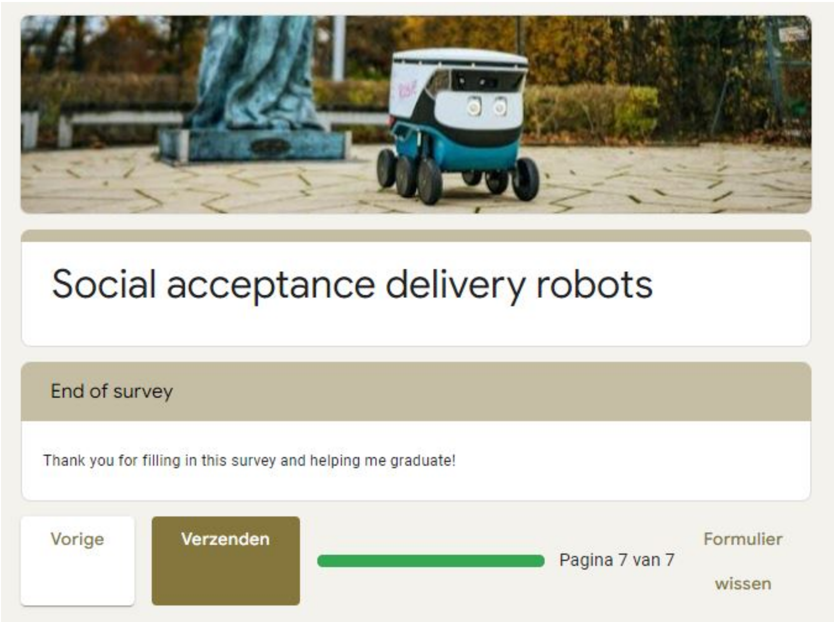

Figure F.7: Survey page 7.

G

Results survey

Respondent 1

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	30%	5	5	5	3
Competence	15%	4	5	3	3
Comfort	35%	5	4	3	4
Dimensions	20%	4	3	3	2

Respondent 2

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	30%	5	4	4	5
Competence	30%	3	3	4	5
Comfort	15%	3	4	3	3
Dimensions	25%	4	4	3	3

Respondent 3

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	20%	3	4	5	5
Competence	30%	4	4	5	5
Comfort	30%	4	4	4	4
Dimensions	20%	2	4	5	3

Respondent 4

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	20%	5	3	5	2
Competence	50%	3	5	5	3
Comfort	20%	3	3	4	3
Dimensions	10%	4	5	2	3

Respondent 5

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	30%	4	3	4	4
Competence	30%	3	4	3	3
Comfort	20%	2	3	4	4
Dimensions	20%	4	3	3	3

Respondent 6

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	40%	5	5	5	3
Competence	10%	3	4	5	4
Comfort	10%	3	1	1	1
Dimensions	40%	4	5	5	5

Respondent 7

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	30%	4	5	5	4
Competence	35%	5	4	5	4
Comfort	0%	1	1	1	1
Dimensions	35%	5	3	3	4

Respondent 8

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	20%	4	5	5	5
Competence	30%	4	4	4	5
Comfort	20%	5	5	5	5
Dimensions	30%	4	4	5	5

Respondent 9

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	25%	4	4	4	3
Competence	25%	4	5	4	3
Comfort	35%	3	3	4	2
Dimensions	15%	3	4	3	2

Respondent 10

		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Predictability	30%	5	5	5	5
Competence	20%	3	3	2	3
Comfort	40%	4	2	4	4
Dimensions	10%	2	4	3	2

Figure G.1: Results of the survey per respondent.