Feasibility Study of Driverless Maintenance in Highway Construction Zones

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Feasibility Study of Driverless Maintenance in Dynamic Highway Construction Zones

by

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This research project was carried out in order to satisfy the requirements for the degree of Master of Science in Construction Management & Engineering in the faculty of Geoscience and Civil Engineering at Delft University of Technology. The topic of this study is the feasibility of implementing driverless maintenance in highway construction zones, which attracted Rijkswaterstaat, the Dutch Ministry of Infrastructure and Water Management, and obtained support from this government institution.

Above all, I would like to thank my master thesis committee. I am grateful for being able to conduct such an original and innovative project. Without Dr. ir. Haneen Farah, I won't have the opportunity to launch my research. I would also like to thank her for her knowledge, patience and support during the past 7 months. In addition, I enjoyed every single discussion with Bert Elbersen, my supervisor from Rijkswaterstaat, who gave me lots of insights into highway work zones. His stories were always full of wisdom, which inspired me to be a better person in both work and life. I would like to thank Dr. ir. Jan Anne Annema as well. I cannot complete cost-benefit analysis without his help. And his encouragement was always important to me, especially when I felt unconfident about my research. Furthermore, I would like to thank my chairman, Dr. ir. Bart van Arem. His feedback and advice were always insightful, which kept me reflecting and improving myself.

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When I first visited the real highway work zone on A12 with one of my interviewees, we put the cones along the emergency lane with cars and heavy trucks roaring and passing by us. We cannot tell how fast the traffic flowed but once we stepped outside the maintenance vehicle, the loud noise and strong gust warned us of the danger. I was just exposed to the dangerous working environment for 10 minutes and I felt nervous and uncomfortable. How do road workers feel, who need to perform frequent tasks in such condition?

Researches have found out that the existence of construction zones on highway could raise the crash rate by around 20%. To be more specific, during 2000-2009, 2% of all fatal traffic accidents in the Netherlands involved work zones. During 1999 and 2013, at least 22 collisions were observed, in which 23 victims were involved and 5 of them lost their lives. Due to the huge speed variance between road users and road workers, the latter is more vulnerable. During the site visit, my interviewee told me that he always felt unsafe at work. Apart from safety, efficiency is another key word when it comes to highway construction zones. Speed limit and sometimes lane closure is necessary in order to protect both road workers and road users. However, the road capacity is also reduced, leading to congestions and delay.

Given the negative traffic impact of highway construction zones, Rijkswaterstaat, the Dutch Ministry of Infrastructure and Water Management, considers to replace road workers with driverless maintenance vehicles. This innovative idea was brought up based on the safety culture of Rijkswaterstaat.

![Safety Culture Ladder of Rijkswaterstaat](image)
As Figure 0.1 shows, there are five levels in the safety culture ladder and Rijkswaterstaat is currently located at the third level, calculative safety culture, which conducts cost benefit analysis to determine whether to take safety measures or not. And the goal of this institution is to move forward to the fourth level, proactive safety culture, which requires safety measures before possible accidents. Driverless maintenance is such a method to realize the objective.

Apart from the Netherlands, other countries have launched research projects on driverless maintenance as well. For instance, both Germany and America have successfully conducted pilot tests for driverless protection vehicles. Russia has developed a driverless marking painting vehicle and Japan is working on the development of a driverless tunnel lighting cleaning vehicle and a driverless snow plow vehicle. These countries are regarded as pioneers in the field of driverless maintenance and could serve as ideal destinations for study tours.

But before learning from other countries, it is crucial to investigate the feasibility of implementing driverless maintenance in the Netherlands. The first interesting question is which parties should be involved in driverless maintenance development. In this study, 9 stakeholders were identified, including The Ministry of Infrastructure and Water Management, road authority, vehicle authority, contractors, manufacturers, research institutions, road users, road workers and insurance companies. 20 interviewees were selected from these parties to collect their opinions of driverless maintenance. It turned out that The Ministry and road authority have high interest and power in the development of driverless maintenance. They also have necessary resources for the development, in particular the political resources, which is crucial to allow the implementation of driverless maintenance. Another government institution, vehicle authority, has relative low interest. As for market parties, contractors and manufacturers have high interest but relative lower power in this issue. Even though they own some financial and technical resources, they won’t be allowed to enter the market without the permission of the government. Research institutions, road users, road workers and insurance companies have relative low interest and low power. Their influence would not be significant unless they form internal or external alliances. For instance, the unions of road users or road workers do own a certain political power. Based on the attributes of different stakeholders, which were summarized and compared in a stakeholder matrix and a power-interest grid, various involvement strategies were provided. It was also recommended that government institutions and market parties should enter into joint efforts to mitigate political risks, bureaucracy and lack of motivation. But before that it is crucial to find a partner, who shares similar safety culture.

In addition, stakeholders need to be convinced that it is worthwhile to invest on driverless maintenance and the implementation of this plan won’t make the safety of work zones even worse. Hence, the traffic impacts and societal cost and benefit were also investigated in this study. As Figure 0.2 demonstrates, a decision-making system for driverless maintenance was built. Interviews were not only utilized to collect opinions of stakeholders but also applied to construct driverless maintenance scenarios with experts. In each scenario, simulation parameters and CBA parameters were input for conducting simulations to investigate the impact on traffic safety and traffic efficiency, and to perform cost-benefit analysis, calculating
the societal net present value of certain driverless maintenance practice and discussing the sensitive influencing factors. The combination of the results of traffic impact analysis and that of economical feasibility investigations leads to an evaluation solution to potential driverless maintenance implementation. In this study, this decision making system was merely practiced for driverless mowing scenario but it is general for the assessment of all driverless maintenance projects.

Two maintenance activities, mowing and marking painting, were expected to realize driverless maintenance in the near future in the Netherlands. In addition, driverless mowing and driverless marking painting were expected to experience significant changes in traffic conditions, in particular the speed limit in work zones, working speed of maintenance vehicles, lane changing behaviors of road users. Microscopic simulations with VISSIM were conducted to compare traditional mowing and driverless mowing based on the inputs of changing parameters. The outcome of simulations revealed that in terms of traffic efficiency, driverless mowing could raise the average speed of road users and reduce their average travel time and average delay. In addition, the emissions and fuel consumption of road users would increase as well. As for traffic safety, driverless mowing could reduce the headway and speed difference of vehicles. But these impacts are not significant under 95% confidence level. Hence it is concluded that driverless mowing is beneficial to the safety of road workers and traffic efficiency. But the impact of the safety of road users is uncertain yet.

Figure 0.2 Decision-making System of Driverless Maintenance
The outcome of cost-benefit analysis revealed that whether driverless maintenance is economically feasible or not depends on the its improvements on safety to a large extent. Take driverless mowing as an instance, an annual saved light injury is not enough to end up with a positive net present value. But if one severe injury or one death could be saved during the life cycle of the driverless mowing vehicle, the investment is cost benefit effective. It should be noticed that the cost-benefit analysis conducted in this study is very much preliminary, not taking into account a variety of variables and risks identified in the calculations. But it provided an overview of the composition of costs and benefits of implementing driverless maintenance and revealed the most important influencing factors.

It is concluded that driverless maintenance in dynamic highway construction zones is conditional feasible. Even though it casts positive impact on traffic efficiency of road users and safety of road workers, its influence on the traffic safety of road users requires further investigations and a positive societal net present value is largely depending on the safety improvements. In addition, it also requires an elaborated stakeholder engagement plan, in which efforts of government institutions and market parties should be combined to utilize necessary resources and to satisfy various interest.

Apart from answering the research questions, this study also made some scientific contributions, including providing an updated literature review of driverless maintenance development, building a stakeholder analysis framework and constructing a decision making system for driverless maintenance. In practice, this study pointed out the direction of future research and investment on driverless maintenance, including the suitable maintenance activities for testing and the targeted countries for learning. In addition, the opinions from the real world were collected to promote the mutual understanding of different parties. Thirdly, accompanied traffic measures with the implementation of driverless maintenance were also discussed, including the adjustment of speed limit and working speed of maintenance. Last but not least, a reference for cost-benefit analysis was provided.

Based on the outcome of this study, five recommendations were offered. To begin with, the database for highway construction zones, including the configuration of work zones and the incident data involved. In the next place, the literature review of driverless maintenance should be updated and conducted in a multi-language source. Additionally, the amount of interviewees, who participate to provide inputs for the decision making system, could be larger and more diverse. Furthermore, traffic simulations of more complicated maintenance activities and road conditions could be explored in the future. Finally, the cost benefit analysis could be improved when an increasing amount and variety of data is available in the future, if the database of highway construction zones would be built and more diverse and advanced traffic simulation would be conducted.
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1. Introduction & Research Design
This project can be regarded as an interdisciplinary one, involving construction management and transport planning fields. The feasibility study of driverless maintenance in dynamic highway construction zones focused on stakeholder analysis, traffic impact analysis and cost-benefit analysis. In this section, the background and problem statement of the research were explained and the research design was described, including research questions, research objectives and research methodology.

1.1. Background and Problem Description

Kroft & Venema (2016) pointed out that road work sector was one of the most dangerous work sectors in The Netherlands, which also caused the highest death rate in incidents among other construction sectors (Van Der Klauw et al., 2010). Statistically, 2% of all fatal collisions in The Netherlands during 2000-2009 turned out to occur in construction zones (Weijermars, 2009). In highway regions, the construction zones post even more danger for both road users and road workers due to high speed. It is also possible that highway construction zones force a temporary close of a lane, which reduces the space for passing vehicles or generates blind zones for dense traffic volumes.

Among the crashes taking place in construction zones, the rear-end crash was the dominant type (Yang et al., 2014; Van Gent, 2007). In dynamic highway construction zones, a road work vehicle conducts the construction or maintenance, followed by a rear protection vehicle, which serves as a warning of ongoing road work and speed reduction. The rear protection vehicle is, therefore, vulnerable as exposed to potential collisions. Compared to the road users, the road work vehicle and the protection vehicle drive in a much slower speed, which posts a great danger for the workers. Even though there are already some mitigation measures, including speed limits and warning signals, trying to improve the safety of work zones, the fatal rate of incidents is still a serious issue. These mitigation measures are likely to reduce the probability of accidents, however, the consequence of crashes is thought to be hardly changed. Once an accident happens, the traffic safety and efficiency in the vicinity will still be heavily influenced. Due to the inevitable accidents involving road workers, driverless maintenance in highway construction zones attracts increasing sights, in which road workers could be partly or entirely replaced by automated driving vehicles so that in spite of collisions no workers would be harmed. In addition, there is a possibility that the driverless maintenance could promote the working efficiency. However, the feasibility of implementing such driverless maintenance is not yet investigated. For instance, on which conditions could driverless maintenance meet the requirements of stakeholders and could be implemented? And the impact of introducing driverless maintenance on traffic safety and efficiency in work zones is still uncertain. Furthermore, the influence of economic factors and on the driverless maintenance plan remains unknown as well.

1.2. Research Questions

Considering the problem statement claimed above, this research was a feasibility study of driverless maintenance in dynamic highway construction zones. In addition, the focus of the feasibility study would be laid on traffic impact analysis (Transport & Planning perspective) and stakeholder analysis & cost-benefit analysis (Construction Management & Engineering
perspective). Hence, the main research question of this project could be interpreted as follows:

What is the feasibility of driverless maintenance in dynamic highway construction zones in terms of stakeholder involvement, traffic impacts and economic factors?

In order to provide an answer to this main question, it is necessary to decompose it into several sub-questions, which could contribute to a more structured and logical problem solving process and more convincing and reasonable solutions. Five research sub-questions were identified:

(1) **How do highway construction zones affect the traffic safety and efficiency currently?**
   The first sub-question was set to develop an overview of current traffic impact of highway construction zones, including the investigation of traffic safety and efficiency. This current situation was examined, in order to serve as a background of introducing driverless maintenance and to be compared with the situation where driverless maintenance is implemented afterwards.

(2) **What are the current and future potential applications of driverless maintenance in dynamic highway construction zones?**
   The second sub-question was aimed to investigate how is driverless maintenance implemented in reality at the present period and other possibility of driverless maintenance in the future so that an overview of the development of driverless maintenance could be provided.

(3) **How are related stakeholders involved in the driverless maintenance?**
   This sub-question aimed at conducting a stakeholder analysis for the implementation of driverless maintenance. By doing so, stakeholders involved would be identified and based on their interest, resources etc., and stakeholder engagement strategies could be planned. In addition, as Figure 1.1 demonstrates, the Safety Culture Ladder (Hudson, 2007) provided 5 different levels of maturity in safety of organizations. The lowest level is a pathological safety culture, which does not care about incidents and just lets it be. The second level is a reactive safety culture, which only takes measures after accidents happen. The third level is a calculative safety culture, which conducts cost benefit analysis to determine whether to take safety measures or not. The fourth level is a proactive safety culture, which requires safety measures before possible accidents. The highest level is a generative safety culture, which means safety is rooted in the organization's business culture and must be guaranteed. Driverless maintenance is a method aiming at achieving proactive safety culture. However, stakeholders will make different decisions based on their own safety culture. Hence, it is crucial to understand the gap between different stakeholders in safety culture and investigate the influence of safety culture on the involvement of stakeholders.
What is the expected impact of driverless maintenance on traffic safety and efficiency in dynamic highway construction zones?

Based on selected scenarios, where driverless maintenance could be conducted, the impact on traffic safety and efficiency would be explored and compared with the current situation, which was investigated in the first sub-question. The results were able to demonstrate whether improvements in traffic situations could be generated with driverless maintenance, therefore, providing the answer to the feasibility study of driverless maintenance in dynamic highway construction zones in terms of traffic impact.

Is it economically feasible to introduce driverless maintenance in dynamic highway construction zones?

Last but not least, the economical feasibility of driverless maintenance was supposed to be investigated by conducting the Cost-Benefit Analysis (CBA), which was planned to base on the societal perspective.

1.3. Research Objectives

One of the goals of the research is to improve the traffic safety and efficiency in highway construction zones with driverless maintenance. The accidents and the fatal injuries are expected to be reduced through the introduction of driverless technology, leading to safer construction zones. The duration of road work is possible to decrease as well as the working times which can be shifted to night time, contributing to an improvement in traffic efficiency. Apart from this practical purpose, as an interdisciplinary project theoretically, this research
was also designed to explore the possibility of applying automated driving technology into construction management sector, moving the latter towards a more intelligent development. In addition, the potential combination provided in this project could serve as a reference case for future related research.

To be more specific, there were five research objectives based on the decomposition of the main research question, aiming at supporting the research implementation and achieving the research goals. First of all, the characteristics of highway construction zones and their impacts on traffic safety and efficiency would be investigated. In the next step, this project aimed to explore the current applications and future possibilities of driverless maintenance in dynamic highway construction zones. Thirdly, it was planned to construct driverless maintenance scenarios based on a stakeholder analysis. Fourthly, compared with previous situations, the impact of driverless maintenance in certain scenarios was analyzed so that it could be observed if any improvements take place. Last but not least, taking into account the future implementation, the influence of economic factors was thought to be important and, therefore, the cost-benefit analysis was in demand to examine the economical feasibility.

1.4. Research Methodology

According to the sequence of answering the sub-questions, the framework of this research could be organized in the following way, as demonstrated in Figure 1.2. First of all, literature review was conducted in six aspects, including highway construction zones, traffic safety and efficiency in highway construction zones, driverless maintenance in highway construction zones, traffic simulation for highway construction zones, stakeholder analysis in transport and automated driving field and cost-benefit analysis in transport and automated driving field, in order to provide a reference from previous work and a theoretical basis for related research methods such as traffic simulation, stakeholder analysis and cost-benefit analysis. The following research was arranged according to the sequence of sub-questions. The current situations of dynamic highway construction zones and their impact on traffic safety and efficiency were summarized with the literature review. The results of the first sub-question would serve as the background and a basis for comparison with following research. In the next place, the current applications and potential future alternatives of driverless maintenance in dynamic highway construction zones would be investigated based on reviewing past and on-going projects all around the world. Thirdly, a stakeholder analysis (SA) was thought to be conducted with stakeholder analysis theory & methods and interviews with various stakeholders, who were identified based on literature review and a preliminary stakeholder network analysis. Chapter 5 further explained how the stakeholders were identified and how interviewees were selected. The results of stakeholder analysis could be used to develop stakeholder engagement plans and to create driverless maintenance scenarios for traffic impact analysis and cost-benefit analysis (CBA) in the following stage. Fourthly, by conducting simulation and interviews, the expected impact of chosen driverless maintenance scenarios could be analyzed in both quantitative and qualitative way. Finally, the CBA was conducted on the basis of the data obtained from previous steps and interviews to investigate the economical feasibility of driverless maintenance in dynamic highway construction zones.
Main question: What is the feasibility of driverless maintenance in dynamic highway construction zones in terms of traffic impact, stakeholder involvement and economic factors?

Figure 1.2 Research Methodology of This Study
As Figure 1.2 shows, five kinds of research methods were applied in this research, namely literature review, interviews, stakeholder analysis, traffic simulation and cost-benefit analysis.

**Literature Review**
As mentioned above, literature review served as the first step to dive into the topic and provide references and theoretical support. Literature review regarding highway construction zones, traffic safety and efficiency and driverless maintenance was thought to serve as references for following research, such as developing an overview of the characteristics of dynamic highway work zones and their safety and efficiency situations. The investigation framework could be also applied when it comes to exploring current dynamic highway work zones.

The second sub-question was thought to be solved based on literature review. Not only scientific paper, but also projects conducted by companies, information gained from news and symposium were thought to be useful. In addition, a multi-language review was necessary to grasp more knowledge of driverless maintenance practices, including investigations of German, Japanese and Chinese projects whose information was only available in their own languages. Literature review regarding traffic simulation, SA and CBA aimed to provide the theoretical basis of these methods and possible tools for analysis. In addition, the practices in previous work were also beneficial by providing successful experience and identifying limitations of methods.

**Stakeholder Analysis**
As mentioned above, before conducting SA, it was important to apply literature review to learn the procedures and common tools for SA in transport and automated driving sectors. After that, stakeholders involved and their attributes such as interest, alliances, resources and power etc. were identified and analyzed with widely used tools, such as power-interest grid. Based on different perspectives of various stakeholders, some driverless maintenance scenarios, which were thought to be most likely to be implemented, were selected for later analysis.

**Interviews**
Interviews were conducted when dealing with the later three sub-questions. The arrangement of interviews could be demonstrated in Table 1.1.

During stakeholder analysis, interviews were important for collecting the opinions of various parties, which served as the basis of later investigations of the relationship between different stakeholders and the influence of their roles on the implementation of driverless maintenance. In addition, the conditions that stakeholders list were useful to build driverless maintenance scenarios. Based on these scenarios, some qualitative data of the traffic impact and some quantitative data about cost and benefit change in driverless maintenance could be obtained by interviews as well.
Table 1.1 Interviews Arrangement

<table>
<thead>
<tr>
<th>Sub-Questions</th>
<th>Interview Targets</th>
<th>Data Input</th>
<th>Expected Data Output</th>
<th>Number of Targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQ3 (SA)</td>
<td>The Ministry, road authority, vehicle authority, research institutions, contractors, manufacturers</td>
<td>Background and research design of this research</td>
<td>Goals, interest, alliances, resources, power of different stakeholders in driverless maintenance implementations</td>
<td>20 in total</td>
</tr>
<tr>
<td>SQ4 (traffic impact)</td>
<td>Driverless maintenance scenarios</td>
<td>Change in accidents frequency and loss, change in traffic volume, speed, delay, driver behaviors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQ5 (CBA)</td>
<td>Driverless maintenance scenarios</td>
<td>Change of maintenance cost and production cost, change of benefit-cost of externality such as traffic safety and efficiency</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Simulation
Simulation was considered as an option to assess the impact of driverless maintenance on traffic safety and efficiency in this project. Vissim, the software for simulation, was thought to be able to simulate the traffic conditions in work zones. Even though it was not possible to simulate the automated driving maintenance vehicles in work zones, it was feasible to simulate the conditions which were generated by driverless maintenance. For instance, the duration of road work may be reduced and the lanes closed were likely to decrease when driverless maintenance could be implemented. In addition, the driving behaviors of road users could also change, which cast an influence on traffic safety and efficiency in work zones. These different scenarios could be simulated in the software and the results of traffic conditions were compared with the current situations obtained in the first sub-question to observe if improvements would take place.

Cost-Benefit Analysis
Cost-benefit analysis was used to explore the economical feasibility of driverless maintenance in dynamic highway construction zones. According to Jeannotte & Chandra (2005) and Sankar et al. (2006), the impacts of work zone activities consisted of six aspects: traffic safety, traffic mobility (or efficiency), economic considerations, environmental concerns, user cost and maintenance cost of contractors. Hence, CBA in this project would base on these groups as well. Changes of cost and benefit in safety and efficiency could be calculated based on the traffic impact analysis in previous sub-questions. The rest four aspects were investigated by interviewing related stakeholders, expecting quantitative data input. A certain period and discount rate needed to be chosen at first, based on literature review or interviews. The Net Present Value (NPV) method was applied to reflect the economical feasibility of driverless maintenance. In addition, sensitivity analysis could be conducted to examine the influence of different factors on the economical feasibility.
2. Highway Construction Zones and Traffic Safety & Efficiency
This chapter provided a literature review regarding highway construction zones, traffic safety and efficiency in such zones and driverless maintenance, in order to form an overview of related research problems. **Section 2.1** summarized the definition, types, layout and strategies applied of highway construction zones and introduced dynamic highway work zones in particular. **Section 2.2** reviewed the current traffic safety and efficiency situation in highway construction zones and gathered possible mitigation measures dealing with safety and efficiency concerns.

### 2.1. Highway Construction Zones

#### Definition and Types

Construction zones or work zones were the zones where road work is conducted, such as road maintenance, guardrail replacement, mowing etc., involving lane closures, detours and moving equipment occasionally (American Driver & Traffic Safety Education Association (ADTSEA), 2013). According to Reinders (2017), construction zones could be categorized into three types based on the characteristics of road work, namely dynamic and semi-dynamic work zones with moving activities and static work zones with cordon and cones. In the Netherlands, highway construction zones could be also classified depending on different layouts. As Huisman (2008) and Koffrie et al. (2011) described, one type of the Dutch highway construction zones was set up with yellow markings and narrowed lanes, informing road users of road work and speed limits by signs in advance. Vrieling et al. (2014) examined the new type of highway construction zones, in which yellow markings were replaced with white ones with higher speed limits and wider lanes.

#### Layout

The design of highway construction zones should comply with the requirements of CROW (a technology platform for transport, infrastructure, and public space) guidelines (CROW, 2017). As **Figure 2.1** demonstrates, there is a transaction area (inleidende ruimte in Dutch), which serves as an informing and warning function and shows the speed limits and legal commandments before road users come across the construction zone (CROW, 2017). There are a series of factors determining the length of transaction area, including the current road layout, sight distance and discontinuities (Reinders, 2017). After that, a detour sign and cordon are usually set up to protect the work zone (werkvak in Dutch). Similarly, physical separation such as traffic cones (langsafzetting in Dutch) is also applied to separate work zone from traffic area. In the work zone, a buffer area (veiligheidsruimte in Dutch) and a clearance zone (vrije ruimte in Dutch) are regulated in case of work zone intrusion. Both intentional and unintentional intrusion were identified, which were considered as a serious safety threat to road workers (Craig et al., 2018). In the activity area (werkruiimte in Dutch), road workers perform working and machinery functions.
There is a bit difference between the highway construction zone layout between America and the Netherlands. As Figure 2.2 shows, in front of the transaction area, there is an advanced warning area, which provides drivers with longer reaction time. In addition, at the end of the work zone, a termination area is identified to inform the road users of the end of construction zone and traffic is allowed to resume normal operations gradually (Manual on Uniform Traffic Control Devices (MUTCD), 2009). For each section, MUTCD (2009) made very specific regulations. For instance, the advanced warning area should be more than 450m for open highway and even more than 800m on freeways and expressways. The first effective sign in this section is supposed to be at the distance of 1.50-2.25 times the speed limit (km/h) before the shoulder taper.

Strategies
Apart from a reasonable construction zone layout, there were also so-called work zone strategies helping control the traffic around construction zones. Mahoney et al. (2007) summarized nine strategies, including alternating one-way operation, detour, diversion, full
road closure, intermittent closure, lane closure, lane construction, median crossover and use of shoulder. The choice of strategies depended on a variety of factors, involving the number of lanes, geometric and structure design, capacity and queues and cost etc. (Mahoney et al, 2007).

Combined with various work zone strategies, the layout of highway construction zones should separate the traffic and work clearly on one hand and save buffer areas for both road workers and road drivers, who leave their dedicated areas by accident or deliberately (Bryden & Mace, 2002).

Dynamic Highway Construction Zones

Dynamic construction zones are special for moving activities and are more likely to witness driverless maintenance. The reason is that in static work zones it makes no difference to involve automated vehicles in maintenance because the maintenance vehicles would just stop in the work zones with road workers leaving the vehicles to conduct maintenance. However, in dynamic work zones, maintenance vehicles keep moving with road workers sitting on them. If they could be replaced with driverless ones, road workers could be saved from possible crashes.

Based on the characteristics of maintenance activities, dynamic construction zones could be classified into two groups: continuously mobile work zones, such as sweeping and mowing, and intermittently mobile work zones with short stops, such as pothole patching and guardrail replacement (Washington State Department of Transportation, 2018). According to the locations where maintenance takes place, dynamic construction zones could be identified in three categories: maintenance on a shoulder, maintenance on a two-lane road, maintenance on a multi-lane road (MUTCD, 2009).

![Figure 2.3 Three Types of Dynamic Highway Construction Zones in USA (MUTCD, 2009)](image-url)
As shown in Figure 2.3, the left situation presents maintenance on a shoulder, where a shadow vehicle or a protection vehicle follows a work vehicle with limited working area on a shoulder. It is regulated that an advance warning sign is supposed to be placed at less than 5 miles before the work zone when the length of the work zone is not too long. The middle scenario demonstrates maintenance on a two-lane road, where both the work vehicle and protection vehicle should display flashing or strobe lights. In certain periods, the two vehicles are supposed to pull over to make way for vehicular traffic. The right situation shows maintenance on a multi-lane road, where a work vehicle and two protection vehicles are put into use. Both shadow vehicles should carry an arrow panel and the shadow vehicle 2 need to display a lane closure sign. This type of maintenance is normally conducted during off-peak period.

Similarly, regulations on dynamic work zones could be found in Maatregelen op autosnelwegen (Measures on motorways) (CROW, 2017). Three major situations are discussed, namely only shoulder is occupied, both shoulder and the right side lane or the left side lane are occupied and multiple lanes are occupied.

In the first situation, as demonstrated in the left picture of Figure 2.4, maintenance work takes place only on the shoulder and following requirements must be satisfied.

When road workers need to leave the vehicle and conduct the tasks,

1. There must be at least one protection vehicle on the shoulder at approximately 100 meters before the zero point (nulpunt). The number of protection vehicles depends on the speed variance, which should be lower than 50 km/h. For instance, when the speed limit before the work zone is 130 km/h while that in the work zone is 70 km/h, which means the speed difference is higher than 50 km/h, it is necessary to set up another protection vehicle with higher speed limit, such as 90 km/h, at 100 meters before.
2. The speed limit in work zones is 70 km/h.
3. All equipment, work vehicles must be at least 1.10 m outside the edge line.
4. The activity area for road workers who leave the vehicle is maximal 200 meters long.

When road workers stay in the vehicle in the process of maintenance and the work vehicle won’t stay at one place longer than 30 minutes,

1. It is not a must to introduce a speed limit or protection vehicles.
2. The work vehicle must be striking with flashing lights, an action window and yellow alternating lighting.
3. When the work vehicle enters or leave the work zone, flashing lights must be used.

In the second situation, as demonstrated in the middle and the right pictures of Figure 2.4, the side lane and the shoulder are closed for maintenance.

When there are digital signs on the motorway,

1. Same as first situation, the speed limit in work zone is 70 km/h as well.
2. The red cross on the side lane is supposed to be displayed.
3. The distance between the bump absorbers is at least 50 meters and at most 100 meters.

When there are no signs on the motorway,
15

(1) Same as first situation, the number of protection vehicles depend on the speed variance, which is maximal 50 km/h.
(2) In the daytime, warning signs with Variable Message Signs (VMS) may be used.
(3) In the nighttime, warning signs with Variable Message Signs (VMS) must be used.

In the last situation, where multiple lanes are closed due to maintenance work.
(1) The maintenance activities should be performed during off-peak hours and under good visibility conditions.
(2) In the nighttime, not only lane lighting is necessary but also additional warning lighting should be equipped with the work vehicle.
(3) When the work vehicle performs tasks on the right side lane or the left side lane, the regulations is the same to second situation.
(4) When the work vehicle works on the intermediate lane, the traffic is only allowed to pass through one side of the work vehicle. The other side should be occupied by protection vehicles with as many lanes as possible remaining available.

Figure 2.4 Dynamic Highway Construction Zones Regulations in NL (CROW, 2017)
2.2. Traffic Safety and Efficiency in Highway Construction Zones

Highway construction zones were considered as a disruption from normal traffic operations because it was necessary that road users should adapt their behaviors to the changed environment (Godthelp & Riemersma, 1982; Al-Kaisy & Hall, 2003; Vrieling, 2014). Due to this disruption, the traffic safety and efficiency around highway construction zones are negatively influenced.

Crash Rate

In terms of traffic safety, a variety of studies showed that the presence of highway construction zones post threat for the safety of traffic by increasing the frequency of crashes. However, the change of frequency varies in different qualitative researches. For instance, Rouphail et al. (1988) claimed that owing to the construction zone, the crash rate increased by 88% compared with that before the construction. Hall & Lorenz (1989) determined the increase of crash rate during construction period to be 26%. Besides the divergence in crash rate increase, there are even some studies proving a lower crash rate during construction period. In 79 construction zones investigated, Graham et al. (1978) reported 31% of them demonstrated a reduced crash rate. Similar decrease was also found in Jin et al. (2008) and Tsyganov et al. (2003). Yang et al. (2014) concluded that these differences resulted from the multi-factor influence such as traffic condition and construction zone type and misuse of data such as direct use of work zone duration as active construction period. After certain calibrations, Ozturk et al. (2014) applied both descriptive and modeling method to observe the change of crash rate, concluding that compared to previous situation, the construction period witnessed an increase of crash rate by 24.4% and 16.8% respectively in descriptive and modeling researches.

Crash Severity

It is also controversial whether the crash severity in construction zones is much higher or not. Pigman & Agent (1990) and Garber & Zhao (2002) found significant higher severity in construction zones than common areas. Van de Nadort (1994) and Chambless et al. (2002), however, denied the existence of significant difference between work zones and non-work zones. Wang et al. (1996) even reported less severe incidents in construction zones. Due to these distinguished divergences in crash severity of construction zones, more investigations are necessary. Statistically, in the Netherlands, as demonstrated below, SWOV-Factsheet (2010) presented the figures of fatal accidents in road work zones during 2000-2009, which could reflect the crash severity of highway construction zones as well. The amount of the fatal accidents accounted for 2% of all fatal traffic accidents. Based on an inspection of The Dutch Ministry of Social Affairs and Employment, in the 22 collisions in work zones during 1999 and 2013, 23 victims were involved and 5 of them lost their lives (Inspectie SZW, 2014).
Based on The Federal Highway Administration of America, from 1982 to 2014, 24745 (about 750 per year) individuals died in work zone crashes. In 2002, the death number reached the peak of 1186 and after that the number of deaths decreased to an average of 591 from 2008 to 2014. From 2003 to 2015, totally 1571 road workers died in the construction zones and the fatal injuries were 121 per year on average (National Institute for Occupational Safety and Health, 2017).

**Crash Locations**

Based on the layout of construction zones, various studies investigated the exact locations of crashes. The activity area was thought to be the place, where incidents took place most frequently. The frequency was estimated as 70% in Garber & Zhao (2002) and 80% in Pigman & Agent (1990). But there were also studies claiming that the transaction area (Jin & Saito, 2009) and buffer area (Nemeth & Migletz, 1978) witnessed more crashes. Synthesizing the previous studies, Yang et al. (2014) concluded that the activity area and buffer area took account for 55% of crashes in total. The limitations of calculating the distribution of crash locations were also explained in Yang et al. (2014), including different layouts in construction zones, changing layouts in construction process and unreliable data based on incident reports rather than on spatial information.

**Crash Time**

Same as crash severity, researches ended up in three points of view. Arditi et al. (2007) found that construction zones would cause five times higher frequency of fatal crashes at night than in the daytime. However, daytime work zones (Dissanayake & Akepati, 2009), especially during non-peak period (Bai & Li, 2007) were the most hazardous. It was even suggested that construction zones be moved to nighttime conditions because of less risk (Ozturk et al., 2014). Also, no significant difference between day and night was discovered in Ullman et al. (2008).

**Crash Types**

Researches achieved a consensus regarding the type of crash. Rear-end crashes dominated all crash types in most studies. 9% to 14% higher frequency of rear-end crashes was observed in Hall & Lorenz (1989) and this rate increased to 50% in Rouphail et al. (1988). Besides, single-vehicle crashes, angle and head-on crashes turned out to be the main causes.
for fatal incidents in construction zones (Daniel et al., 2000). Side-swipe crashes were identified mainly in transaction area and angular and fixed object crashes were more frequent in activity area and termination area (Garber & Zhao, 2002). The leading position of rear-end crashes revealed the lack of timely warning signs or inappropriate information delivery.

Speed Limits
Based on the requirements of CROW guidelines (2013), the speed limit was reduced by at least 30 km/h to approximately 80-90 km/h in the vicinity of highway construction zones. However, the compliance with these posted speed limits posted in highway construction zones were in a poor situation (Mohammadi & Bham, 2011; Debnath et al., 2014). Jellema (2015) found in selected nine work zones in Friesland Province of the Netherlands, the operational speed was even 20%-40% higher than the speed limit. These speeding behaviors came down partly to unreasonable speed limits without the presence of visible road work (Blackman et al., 2014). It was observed that if this case frequently happened, speed limits would be less convincing to drivers. Hence, speed limit was supposed to be no lower than necessary and the duration of speed limit should be no longer than necessary (Outcalt, 2009). In addition, the speed limit created benefits in terms of safety, however, generated associated penalty in longer travel time, which reduced the traffic efficiency (Mohammadi & Bham, 2011). Minnesota Department of Transportation (2014) also reported that overuse of speed limit would cause less effective traffic and therefore should be prudently applied. Hence, the set of speed limits should also take into account cost-benefit analysis. And during no work period, the speed limit was supposed to be covered or removed (Minnesota Department of Transportation, 2014).

Traffic Volume
Highway construction zones cast a negative influence on traffic efficiency by not only applying speed limits but also by reducing the traffic volume. Various researches proved this by demonstrating the decrease of road capacity ranging from 8% (Ter Kuile, 2006) and 17% (Al-Kaisy & Hall, 2003) and even with a maximum of 24% (Chandra & Kumar, 2003). To be more specific, with lanes closure involved, highway construction zones gave rise to traffic congestions, delay and increased emissions (Borchardt et al., 2009; Du & Chien, 2014). In America, approximately 10% of congestion in highway came down to construction zones (FHWA, 2005). And the congestion led to $700 million lost in fuel consumption every year (FHWA, 2012). Furthermore, as the congestion extended beyond the lane closure signs, the safety concern involving rear-end crashes, in turn, would become more serious for work zones (McCoy & Pesti, 2001).

Mitigation Measures
Given the negative impact of highway construction zones on traffic safety and efficiency, a variety of mitigation measures has been investigated or implemented in previous studies.

Speed management, which has its own framework and logical order actions (Wegman et al., 2008; Van Schagen & FeyPELL, 2011), is a common solution dealing with the side effect of
highway construction zones. According to SWOV (2016), there were six procedures regarding speed management, namely (1) Determine the safe speed limit; (2) Make sure the limit is credible; (3) Give good information about the local speed limit; (4) Support the limit with speed inhibitors; (5) Police enforcement and (6) Education and information. In the Appropriate Speed saves All People (ASAP) project, speed management measures were also adjusted depending on road type, work type and implementation locations such as transaction area, activity area etc. (Vadeby et al., 2016). It was also suggested that the speed management framework should move forward a flexible and dynamic program by applying Intelligent Transport System (ITS) (Wegman et al., 2008). ITS is a bundle of information and electronics technologies for communication purposes, which could be used to improve the safety and efficiency around construction zones (Ullman et al, 2014). Four components were identified in this system, including sensors gathering existing data, communication systems enabling data transfer, software analyzing and documenting data and electronic equipment conveying messages to end users and conducting traffic management decisions (Ullman et al, 2014). With the help of ITS, speed limit could be easily adjusted based on the situation of work zones and be timely conveyed to drivers, who could adapt their behaviors in turn.

Combining speed management measures, Abdelmohsen (2016) also took into account the layout of construction zones to minimize the probability of crashes. A crash index (CI) was built to reflect the contributions of various factors:

\[
CI = (\beta_{\text{speed}} \times \beta_{\text{CT}} \times \beta_{\text{SH}} \times \beta_{\text{LC}} \times \beta_{\text{D}} \times \beta_{\text{TTC}} \times \beta_{\text{AE}}) \times \beta_{\text{WL}} \times \beta_{\text{L}}
\]

In order, these indicators represented the probability of crashes owing to speed limits, construction start time, available shoulder width, lateral clearance, construction zone duration, temporary traffic control measures, access and egress method, width of the live traffic lane and the effective length of the construction zone, respectively. In the application, in order to achieve the minimum CI, the importance of indicators was supposed to be ranked and a repeated process was expected (Abdelmohsen, 2016). This plan not only pointed out the places or directions, where improvements could be made but also quantified the change for an optimization.

There were also some studies focusing on the physical separation of construction zones. Beason et al. (1984), Ullman et al. (2004) and Ullman et al. (2005) examined the possibility of replacing concrete barrier with more portable and movable barrier, such as vehicle-mounted mobile barriers, steel barriers and water-filled barriers etc. It turned out even though these kinds of barriers could generate larger lateral displacement and cost more, they could be more easily and quickly installed, removed and transported so that the duration of construction period would be reduced (Ullman et al., 2011). El-Rayes et al. (2013) assessed the application of rumble strips to provide an auditory and vibratory warning in field experiments, where it was concluded that the rumble strips, which were located before or at the edge of construction zones, could generate adequate sounds to warn drivers of the occurrence of construction work.
Another widely used positive protection method was to introduce rear protection vehicles with truck-mounted attenuators, which could absorb the impact energy of rear-end crashes and protect the working vehicles (Ullman et al., 2011). Nevertheless, as crashes take place, the driver of the protection vehicle could also be harmed. Hence, automated vehicles were thought to be able to contribute to a safer construction zone in spite of the demand for a long period to achieve mature technology and significant market penetration (Bazuin, 2017). The involvement of automated vehicles in road work could be considered as so-called driverless maintenance in highway construction zones, which would be further explored in next section.

![Figure 2.6 Rear Protection Vehicle © copyright: Hessen Mobil](image)

### 2.3. Summary

First of all, this chapter has discussed the layout regulations for highway work zones, both static and dynamic situations. These rules serve as the basis of highway maintenance work and should be taken into account when applying driverless maintenance.

In the next place, literature review showed that the existence of construction zones did cast negative influence on both traffic safety and efficiency. Due to this situation, various mitigation measures have been applied. However, considering that the risk is that the probability of an accident multiplies the consequence of the accident, all the measures applied focus on reduce the probability of an accident and generate no impact on the consequence of the accident. Hence, the application of driverless maintenance, namely maintaining the highway with driverless working vehicles, is considered to weaken the consequence of the accident. The next chapter will discuss the current researches on driverless maintenance and future driverless maintenance possibilities.
3. Driverless Maintenance in Highway Construction Zones
Driverless maintenance is a term originated from this proposed research, which means the involvement of driverless vehicles in highway work zone maintenance. The key goal of driverless maintenance is to achieve an automation of road maintenance and prevent road workers from potential crashes. In recent years, a series of attempts have been made to move road maintenance work towards automation, including automated equipment, driverless vehicles and even robots.

Osmani et al. (1996) built an evaluation framework for automated road maintenance, in which three phases were organized, namely needs assessment & conceptual feasibility phase, technology feasibility evaluation phase and field testing phase. In the first phase, seven factors, including productivity, quality, safety, sociopolitical, technology feasibility, working environment and user-costs & emissions, were discussed for a series of maintenance activities by experts. It was concluded that 13 activities were likely to be conducted automatically, such as pothole repairs, guard fence maintenance, paint and bead striping etc., among which most activities were mobile. Another article (Skibniewski et al., 1990) also revealed that these kind of continuously performed maintenance tasks, including snow removal, grass mowing, brush cleaning etc. could be part of the automation development. Hendrickson & Au (1989) explained the basis for automation in road construction and maintenance, which consists of manipulators, end effectors, motion systems, electronic controls and sensors.

The manipulator arms were able to move end effector to proper location or work object with appropriate speed and six axes of movements (right/left, forward/back, up/down, pitch, roll and yaw) (Hendrickson & Au, 1989). The end effectors were supposed to execute complex tasks with the help of manipulators. Common and typical end effectors include sprayers, scrapers and sensors etc. (Hendrickson & Au, 1989). Motion systems provided a platform to support the movement of automation equipment, in which the driverless vehicles are good instances. Electronic controls consisted of hardware and software units, which control and coordinate the movement of manipulators and end effectors. Sensors were applied to change a variety of environmental information (mechanical, optical, electrical, acoustic, magnetic etc.) into electrical signals, which were used to make decisions in movements and operations (Hendrickson & Au, 1989).

Based on the identified maintenance activities and the composition of automation technology, current automation practices could be summarized in Table 3.1.
<table>
<thead>
<tr>
<th>Year</th>
<th>Practices</th>
<th>Automation Components</th>
<th>Maintenance Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>Multipurpose traveling vehicle (Point, 1988)</td>
<td>Manipulator, end effector, electronic controls</td>
<td>Mowing</td>
<td>It can save up to 50% on mowing costs</td>
</tr>
<tr>
<td>1995</td>
<td>Automated pavement marking applicator (Bernold &amp; Moon, 1995)</td>
<td>Manipulator, end effector, electronic control, sensor</td>
<td>marking painting</td>
<td>It could use a remote video system to view the road surface and move the cursor to place the marking</td>
</tr>
<tr>
<td>1998</td>
<td>Remotely driven shadow vehicle (FOCUS, 1998)</td>
<td>Motion system, electronic control, sensor</td>
<td>Protecting the work vehicle</td>
<td>It was a prototype from The Minnesota Department of Transportation, which allows a driver control the shadow vehicle remotely to protect the working vehicle.</td>
</tr>
<tr>
<td>2000</td>
<td>Automated crack sealer (Kim et al., 2000)</td>
<td>Manipulator, end effector, electronic control, sensor</td>
<td>Crack sealing</td>
<td>It could acquire the image of cracks and map the locations and afterwards seal the crack</td>
</tr>
<tr>
<td>2004</td>
<td>Robotic traffic cones (Bauer, 2004)</td>
<td>Motion system, electronic control</td>
<td>Traffic cones placing</td>
<td>It could be moved remotely with the electronics and motors in the base</td>
</tr>
<tr>
<td>2007</td>
<td>Autonomous Weeder Platform (Tijmen &amp; Mustafa, 2007)</td>
<td>Manipulator, end effector, motion system, electronic control, sensor</td>
<td>Asphalt cleaning in shoulder, ditch cleaning, traffic assistance</td>
<td>It could fulfil road cleaning task and traffic assistance. It was under development in Wageningen University</td>
</tr>
<tr>
<td>2011</td>
<td>Longitudinal crack sealing machines (Shreve, 2011)</td>
<td>Manipulator, end effector, electronic control, sensor</td>
<td>Patch filling and cracks sealing</td>
<td>It could fill cracks at up to 5 miles per hour</td>
</tr>
<tr>
<td>2013</td>
<td>Road paving robots (Deb, 2013)</td>
<td>Manipulator, end effector, electronic control, sensor</td>
<td>Road paving with asphalt</td>
<td>It could complete tasks based on an artificial vision and a laser range sensor</td>
</tr>
<tr>
<td>2013</td>
<td>Automated tunnel lighting fixture cleaning vehicle (Central Nippon Expressway, 2013)</td>
<td>Manipulator, end effector, motion system, electronic control, sensor</td>
<td>Tunnel lighting fixture cleaning</td>
<td>It could perform the cleaning task at the speed of 80km/h</td>
</tr>
<tr>
<td>2014</td>
<td>Automated cones placing vehicle (CarWatch, 2014)</td>
<td>Manipulator, end effector, electronic control, sensor</td>
<td>Traffic cones placing</td>
<td>It could place and remove the cones and it was under development in Japan</td>
</tr>
<tr>
<td>2015</td>
<td>Driverless Protection Vehicle (Stolte et al., 2015)</td>
<td>Motion system, electronic control</td>
<td>Protecting the work vehicle</td>
<td>It realized the shadow vehicle prototype and was under development in Germany</td>
</tr>
<tr>
<td>2016</td>
<td>Self-driving Marking Painting Vehicle (STiM Company, 2016)</td>
<td>Manipulator, end effector, motion system, electronic control, sensor</td>
<td>Lane marking painting</td>
<td>It is a product from STiM Company, Russia and it is on a road test</td>
</tr>
<tr>
<td>2017</td>
<td>Remotely controlled impact protection vehicles (Rathner, 2017)</td>
<td>Motion system, electronic control, sensor</td>
<td>Protecting the work vehicle</td>
<td>It is America's first automated driving protection vehicle</td>
</tr>
<tr>
<td>2017</td>
<td>Automated snow plow vehicle (NEXCO, 2017)</td>
<td>Manipulator, end effector, motion system, electronic control, sensor</td>
<td>Sweeping the snow</td>
<td>It is under development in Japan</td>
</tr>
</tbody>
</table>
Different varieties of automation implementation were summarized, in which the maintenance activities involved were all dynamic. However, the equipment of motion system determined whether the practices are full automation or not. For instance, even though the automated crack sealer in America (Kim et al., 2000) was supposed to fulfil automated pavement crack and joint sealing and was going to be developed to be applied in other maintenance activities, such as pothole filling, marking placement after adjustments, these machines still need a driver to move to next work area, which means the danger for workers still exists.

Hence, merely the practices in bold and italic with motion system are full-automated and could be regarded as driverless maintenance. There are 8 practices equipped with motion system. But the robotic traffic cones (Bauer, 2004) were not included in driverless maintenance because of the lack of vehicles. The rest 7 driverless maintenance projects could be categorized into 5 types, namely autonomous weeder platform (the Netherlands), automated tunnel lighting cleaning vehicle (Japan), driverless protection vehicle (Germany, America), self-driving marking painting vehicle (Russia) and automated snow plow vehicle (Japan).


In this section, the five types of driverless maintenance in current practices mentioned above were further described, including their design, working conditions and working mechanisms etc. Based on the current driverless maintenance practices, more possibilities in the future were discussed in next section.

Autonomous Weeder Platform (The Netherlands)

This project was conducted by Wageningen University and supported by Adviesdienst Geo-Information and ICT (AGI) in 2006, in order to explore the possibility of automation of road management and maintenance. There were two phases of research in this project, including the feasibility study and road test.

In the feasibility study, it was assumed that the large amount of geo-information of road networks from Rijkswaterstaat (The Ministry of Infrastructure and environment, the Netherlands) could be beneficial to the automation. Based on the available data and technology at that time, it was concluded that possible automation in road maintenance includes asphalt cleaning in shoulder, asphalt edge cleaning, ditch cleaning and traffic assistance, such as moving with traffic management measures and signs. At that time, full-automated mowing was not possible because trees formed obstacles when the machine worked along the grass. The geo-information provided by Rijkswaterstaat was not always accurate enough for the machine to detect the location of trees. Hence, further technical development and research were necessary to achieve driverless mowing.
In the road test, the autonomous weeder platform from Wageningen University was assessed in several maintenance scenarios. This invention was originally applied in controlling weed in agriculture field to achieve non-chemical requirements. It was equipped with a GPS receiver and two antennas so that this platform could not only measure the location but also orientate itself accurately. In this test, this platform was further equipped with a hydraulic lifting device and a hydraulically driven sweeping rush, in order to fulfil the task of cleaning the edge of asphalt road. A series of hardware and software was installed as well to operate the added equipment. The test took place along the highway A30 and A50, which turned out to be great success because the platform was able to follow the edge of asphalt road accurately with its sweeping brush. Another road test involved operating the platform as a moving traffic barrier for traffic assistance. In this scenario, the platform followed the route where maintenance activities were conducted and warned road users of the work zone. It was concluded that this application could only be successful when the road safety was guaranteed.

Automated Tunnel Lighting Fixture Cleaning Vehicle (Japan)

This project was conducted by Naka Nippon Expressway and Japan Automobile Research Institute in 2013. It was the first attempt in Japan to introduce automated driving technology into road maintenance.

Before this vehicle, the cleaning task of tunnel lighting fixture required both brushes and humans. In addition, it was necessary to close lanes and the cleaning time last long, as the left part of Figure 3.2 shows. The automated tunnel lighting fixture cleaning vehicle combines automated driving technology and cavitation cleaning technology to replace humans and brushes (the right part of Figure 3.2). Technically, this vehicle could identify the lines of lanes and drive along the lines with the help of cameras both in front of and in the back of the vehicle. In terms of cleaning, the cavitation technology could clean the lighting fixture in a shorter time without the use of brushes. Furthermore, this vehicle was able to fulfil the cleaning task accurately at the driving speed of 80km/h, which could reduce the working period and improve the congestion effectively.

Figure 3.1 Autonomous Weeder Platform (Wageningen University, 2007)

Automated Tunnel Lighting Fixture Cleaning Vehicle (Japan)

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Driverless Protection Vehicle (Germany, America)

In 1998, the prototype of a remotely driven shadow vehicle was brought forward, allowing a driver to conduct remote control on the operation of the shadow vehicle with a portable computer (FOCUS, 1998). The prototype was realized in Stolte et al. (2015), Germany, in which the rear protection vehicle worked in four different operation modes, as Figure 3.3 demonstrates. In order to reach the construction zone, the protection vehicle operated in manual mode, where the control of a driver is necessary. Arriving at the work zone, safe halt mode was in effect to make sure that the vehicle stops at the expected spot. During the dynamic work, the protection vehicle would switch to follow mode, following the work vehicle at the certain distance. The coupled mode, where the protection vehicle followed the work vehicle in a close distance, was also designed to avoid the moving lanes behaviors of road users, which could interrupt the connection between the protection vehicle and the work vehicle. Even though the protection vehicle in this project was thought to fulfill the requirements of SAE Level 4, which defined that in certain scenarios, the automated driving system could perform all aspects of dynamic driving task in spite of the appropriate response of a human driver (SAE, 2014), the design of this driverless maintenance system was restricted to performing work only in shoulder and a very low speed, approximately 10 km/h (Kraus, 2018).
Based on the four operation modes mentioned above, Bagschik et al. (2018) identified potential hazardous events by applying an adapted Hazard and Operability Analysis (HAZOP). Stolte et al. (2018) further assessed the consequences of the identified hazardous events according to their severity, exposure, controllability and safety goals, in which expert judgments were involved. Bagschik et al. (2018) and Stolte et al. (2018) concluded that the hazard analysis of driverless protection vehicles could not rely on conventional approaches, such as Hazard and Operability Analysis (HAZOP) or Failure Mode and Effects Analysis (FMEA). The former method failed because in its standard no suitable performance criteria for automated vehicle system could be found. In the latter approach, it was difficult to investigate the effects of driverless vehicles in a complete set of scenes. Furthermore, it was necessary that the identification of events involved the entities of work zones such as road infrastructure, weather conditions etc. and the criteria for evaluating the risk of certain events should be more carefully considered, taking into account expert opinions.

Similar project could be found in America as well. Colorado Department of Transportation (CDOT) tested the first remote-controlled impact protection vehicles in America (Janet, 2017). This vehicle was equipped with truck-mounted attenuators (TMA) and therefore designed to be hit to protect the working vehicle. As Figure 3.4 shows, the leader vehicle transmitted its position, speed and direction to the protection vehicle through wireless link so that the follower vehicle could ride the exact path (RoadX, 2017). In addition, the protection vehicle was equipped with obstacle detection systems to identify the obstacles in its path. CDOT and its partners utilized military technology in this vehicle and tested its capabilities in a field trial, including emergency stopping, obstacle detection, staying in lanes ability and making tight turns ability (AUVSI News, 2017). It turned out that the test was successful and the traffic safety was improved to a new level. This project was considered to lower the maintenance costs and improve the work safety because of free of drivers in the protection vehicle. Furthermore, CDOT was exploring to adapt this technology to other maintenance vehicles, such as sweepers and mowers.

Figure 3.4 Autonomous Protection Vehicle (RoadX, 2017)
Automated Snow Plow Vehicle (Japan)
Snow removal is a tough road maintenance task because of bad weather conditions and long working period. Especially when the visibility is low and the sight is limited, this task requires dense concentration and abundant experience of operators, which is a great challenge for both physical and mental conditions. Hence, NEXCO was trying to develop an automated snow plow vehicle, aiming to set humans free from this danger maintenance activity.

At the present stage, this vehicle was equipped with satellite signal receiver and antenna to acquire geo-information from the quasi-zenith satellite “MICHIBIKI”. As Figure 3.5 demonstrates, there was a guidance monitor in the vehicle, displaying the working information (e.g. the distance from guardrail etc.), current vehicle location, lateral deviation and correction angle. It turned out that the guidance information gained from satellite showed high accuracy with only several centimeters deviation from actual location. With the help of this vehicle, the snow removal task could be operated even though snowstorm takes place, which leaded to low visibility. In addition, previously two workers (a driver with an assistant) were in need to perform the snow removal task in Japan, with this new technology only one operator is enough to complete the job, which also means unfortunately at the present period this vehicle is not yet driverless. However, according to the development roadmap provided by NEXCO, it was designed this vehicle would move towards full automation in the near future.

As Figure 3.6 shows, after 2021, this vehicle was expected to be developed into a full-automated one, namely no driver involved, for both the low speed one (rotary snow plow
vehicle) and the high speed one (snow plow trunk). The technologies involved include 
guidance monitor (as mentioned above) and work operation system & operation control 
support, which is able to make the plow and augers and the vehicle itself operate 
automatically.

<table>
<thead>
<tr>
<th>Automation of Snow Plow Vehicle Roadmap</th>
</tr>
</thead>
<tbody>
<tr>
<td>~ 2016</td>
</tr>
<tr>
<td>Low speed snow plow vehicle/ Rotary snow plow</td>
</tr>
<tr>
<td>Work operation Operation control support</td>
</tr>
<tr>
<td>High speed snow plow vehicle/ Snow plow trunk</td>
</tr>
<tr>
<td>Work operation Operation control support</td>
</tr>
</tbody>
</table>

Figure 3.6 Automated Snow Plow Vehicle Development Roadmap (NEXCO, 2017)

Self-Driving Marking Painting Vehicle (Russia)

STiM Company from Russia developed a type of self-driving road marking machine Kontur 700TPK. A video demonstrated the road test of this machine (STiM, 2016), in which this machine conducted marking painting task without a driver but under supervision from distance, as Figure 3.7 shows.

The marking unit of this machine consists of a tank, a paint pump and a set of paint guns, both on the left side and on the right side of the machine (STiM, 2018). The following figure was presented on the website of STiM Company, explaining the basic specifications of Kontur 700TPK. Currently this machine is sold on the market, however, the operation of it still needs two people. This example shows that even if the driverless marking painting has
achieved success in the pilot test, it is still not mature enough to enter the commercial market. A possible concern is that the real traffic flow could influence the operation of this machine because in the test, this machine works in a completely closed zone without extra safety measures.

### Basic Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kubota engine power, max</td>
<td>63 kW</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Diesel</td>
</tr>
<tr>
<td>Operating speed</td>
<td>1-5 km/h</td>
</tr>
<tr>
<td>Transportation speed</td>
<td>up to 12 km/h</td>
</tr>
<tr>
<td>Maximum operating road gradient</td>
<td>20%</td>
</tr>
<tr>
<td>Burner fuel consumption, max</td>
<td>3.8 l/h</td>
</tr>
<tr>
<td>Line width (paint)</td>
<td>10-20 cm</td>
</tr>
<tr>
<td>Paint tank capacity</td>
<td>700 kg (435 l)</td>
</tr>
<tr>
<td>Bead tank capacity</td>
<td>190 kg</td>
</tr>
<tr>
<td>Line width (plastic)</td>
<td>0.5-40 cm</td>
</tr>
<tr>
<td>Line width</td>
<td>2.0-4.0 mm</td>
</tr>
<tr>
<td>Automatically maintained temperature of plastic</td>
<td>180-210°C</td>
</tr>
<tr>
<td>Thermoplastic tank capacity</td>
<td>700 kg (350 l)</td>
</tr>
<tr>
<td>Overall dimensions (length x width x height)</td>
<td>5.7 x 2.2 x 2.7 m</td>
</tr>
<tr>
<td>Equipped weight</td>
<td>3,500 kg</td>
</tr>
<tr>
<td>Gross weight</td>
<td>4,050 kg</td>
</tr>
<tr>
<td>Personnel</td>
<td>2 persons</td>
</tr>
</tbody>
</table>

Figure 3.8 Basic Specifications of Kontur 700TPK (STiM Company, 2018)

### 3.2. Future Driverless Maintenance Possibilities in Highway Construction Zones

As discussed above, the application of automated driving technology seems to be the last step to help humans get rid of dangerous working conditions. Before that, it is easier to make maintenance activity itself operate automatically, such as mowing, marking painting etc. However, currently the automation equipment still need drivers or operators to decide moving trajectory and to change work zone locations. The so-called driverless maintenance in the future will base on existing available automation equipment. Hence, only combined with automation working equipment, driverless vehicle is able to fulfil maintenance without involving humans. For instance, the automated tunnel lighting fixture cleaning vehicle performs a good combination of cavitation cleaning technology and automated driving technology. One exception lies in the rear protection scenario, where the automated vehicle only needs to follow the work vehicle without performing other tasks.

Based on the road maintenance activity summarized by Osmani et al. (1996), those related with highway are listed in **Table 3.2**. In this table, the label “Automation” means the equipment operating the maintenance work is automated and the label “Driverless” means the moving of the maintenance equipment or vehicle does not need a driver. The last column investigates the possibility of widely applying driverless maintenance for the maintenance activity in the near future, including those, which have already achieved
“automation” or “driverless”. The reason is that when a maintenance activity could be performed with automated equipment, it is easier to achieve driverless maintenance once the automated driving technology is integrated, such as those driverless maintenance practices mentioned in last section.

Table 3.2 Possible Driverless Maintenance Activities in Highway Work Zones

<table>
<thead>
<tr>
<th>Maintenance Activity</th>
<th>Automation</th>
<th>Driverless</th>
<th>Possibility of DM with AV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leveling or overlay</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Mowing</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Paint and bead striping</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Install or reinstall signs</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Base removal and replacement</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Signal maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Litter removal (asphalt cleaning)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Pothole repairs</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Illumination (cleaning)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Strip or spot seal</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Assistance to traffic (protection vehicle)</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Guard fences</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Miscellaneous sign maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Culvert maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Aggregate seal coat</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Miscellaneous roadside maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Ditch maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Rest area maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Sealing cracks and joints</strong></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Reshaping ditches and slopes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Driveway maintenance</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

DM: driverless maintenance; AD: automated vehicle

Among all the maintenance activity listed in Table 3.2, some have already witnessed the automation of the work itself but still wait the possibility of driverless movement, such as mowing and pothole repair etc., others have realized both automation in working and moving at least in pilot tests, therefore actual driverless maintenance, such as litter removal, assistance to traffic (shadow vehicle) etc. However, it needs to be noticed that even these activities receive a “Yes” in “Driverless”, all of them are still in the trial phase and therefore not widely applied. The rest activities still require a large amount of labor efforts and further
research on automation. Hence, in the near future, combining automated driving technology and current automation technology, it is possible to develop the following seven maintenance activities: (1) mowing, (2) paint and bead striping, (3) litter removal (asphalt cleaning), (4) pothole repairs, (5) illumination cleaning, (6) assistance to traffic (protection vehicle) and (7) sealing cracks & joints into widely applied driverless maintenance.

3.3. Summary

In this chapter, driverless maintenance was separated into two phase with two criteria: if the maintenance work could be done automated and if the maintenance vehicle could move driverless. Based on these two criteria, the development of maintenance activity automation was described, in which current driverless maintenance researches and projects were discussed in more detail, including the autonomous weeder platform (the Netherlands), automated tunnel lighting fixture cleaning vehicle (Japan), driverless protection vehicle (Germany, America), self-driving marking painting vehicle (Russia) and automated snow plow vehicle (Japan). This section provided a overview about how highway maintenance sets free human workers with the development of technology.

In the next place, 7 out of 21 highway maintenance activities were identified to have achieved either maintenance equipment automation or driverless maintenance in trials. These 7 maintenance activities were considered to be the most possible driverless maintenance applications in the near future, including:

(1) Mowing
(2) Paint and bead striping
(3) Litter removal (asphalt cleaning)
(4) Pothole repairs
(5) Illumination cleaning
(6) Assistance to traffic (protection vehicle)
(7) Sealing cracks & joints

These activities served as the basis for constructing driverless maintenance scenarios and conducting traffic simulation and cost-benefit analysis in the following stage.
4. Stakeholder Involvement
The introduction of driverless maintenance in dynamic highway work zone serves as a part of transport policy making. Before investigating the traffic impact and economical influence of this plan, it is necessary to conduct a stakeholder analysis to understand which parties are involved and what kind of roles they play during the process of potential implementation of driverless maintenance. The definition, purpose and procedures of stakeholder analysis were further explained in Appendix A.

The introduction of driverless maintenance in highway work zones is a practical issue, which involves a large group of stakeholders. Since the researcher is not the core of driverless maintenance development, it is crucial to understand the lived experience of the parties involved and the meaning they make of that experience (Seidman, 2006). The interest in stakeholders’ stories and inputs is the root of interview technique. In addition, interviews with stakeholders were considered as a useful technique to identify the needs of users and establish requirements (Cohene & Easterbrook, 2005). In this research, the purpose of interviews was to understand the stakeholders’ opinions regarding when implementing driverless maintenance and to imagine the future driverless maintenance applications with stakeholders together.

4.1. Interview Design

The interviews were conducted in two parts. The first part dealt with stakeholder analysis and the second part discussed about driverless maintenance scenarios building. The interviews were semi-structured, in which open-ended questions were asked and discussions and interactions between interviewer and interviewees were more important and frequent. Each interview was recorded after the approval of the interviewee and a feedback report was presented to the interviewee as soon as possible. After the interviewee approved the interpretation of his opinions by the researcher, the insights gained from interviews were incorporated in the research.

In Appendix B the interview protocol can be found. There were two parts in the interview, including (Part A) discussions about stakeholder analysis and (Part B) questions for driverless maintenance scenarios building. In Part A, the interviewee’s knowledge and position towards driverless maintenance were investigated. In addition, in order to fill in the stakeholder matrix and create the power vs. interest grid, questions regarding interest, alliances, resources and power were set up. As for interest, potential advantages and disadvantages of driverless maintenance were asked. It was more direct to ask possible alliances with other parties. As Schmeer (2000) explained, in stakeholder analysis, resources include human, financial, technological, political and other aspects. Hence, in this interview, these aspects were discussed as well. In addition, the availability and mobility of these resources were also taken into account. When it came to power, questions became more indirect. Instead of including “power” in the question, the initiatives to take actions, the ability to persuade other parties, the amount of resources and their availability and mobility were expected to reflect the power of the stakeholder. At the end of Part A, predictions about other parties’ position, interest and power were discussed. Part B of the interview protocol was explained in next chapter.
4.2. Stakeholder Identification

The discussions regarding driverless maintenance are still limited. On the other hand, as a dynamic and rapidly developing topic, it is not one hundred percent certain that a complete list of stakeholders could be provided and widely accepted. However, in previous workshops and studies in the field of automated driving vehicles and transport infrastructure (CARTRE, 2018; Lu, 2018), a reference list of stakeholders could be found. In this section, potential stakeholders involved in the implementation of driverless maintenance were identified based on the previous studies. From the list of stakeholders, 20 interviewees from different parties were reached to collect their opinions of the development of driverless maintenance.

(1) **The Ministry of Infrastructure and Water Management**: The Ministry consists of three sections: policy, implementation and inspection (Government of the Netherlands, 2018). At the highest level, The Ministry is responsible for creating an efficient and safe road network, which is a part of its commitment and directly related to the driverless maintenance application. And related transport policy needs to be implemented by road authorities and vehicle authorities.

(2) **Road authority**: Rijkswaterstaat is the executive agency that makes sure that the policy made by The Ministry of Infrastructure and Water Management is implemented. One of the major responsibilities of Rijkswaterstaat is to facilitate smooth and safe flow of traffic for road users. Road authority may also include provinces and municipalities, which are in charge of the design, construction and maintenance of road networks in their precincts. In order to fulfill the tasks, road authorities will employ contractors to perform the maintenance activities and cooperate with research institutions to develop innovative working methods and equipment.

(3) **Vehicle authority**: the introduction of driverless maintenance involves the application of new-types of maintenance vehicles which are equipped with automated driving technology. The vehicle authority in the Netherlands, RDW, is in charge of supervising, registering and managing vehicles (no matter the vehicles are owned or used by road users, road workers or contractors), therefore it is also responsible for conducting tests and issuing licences for such driverless maintenance vehicles. In addition, RDW is also obliged to implement the policy made by The Ministry of Infrastructure and Water Management.

(4) **Contractors**: contractors enter into contracts with road authorities to conduct road maintenance work. Therefore, they are the party who consumes the driverless maintenance vehicles from manufacturers. They are required to complete the maintenance task in a certain period of time and perform a professional management of the work zones to ensure the safety and reduce the disruption to traffic flow. They may also cooperate with research institutions to improve work efficiency.
(5) Manufacturers: driverless maintenance vehicles are supposed to be produced and sold by manufacturers. This process may involve the cooperation with research institutions.

(6) Research institutions: research institutions are engaged in various researches, such as transport planning, work zone management, automated driving vehicles etc. They are expected to provide technical solutions to driverless maintenance vehicles for different parties, such as road authorities, manufacturers and contractors, or assess the feasibility of driverless maintenance plan.

(7) Road users: road users utilize and enjoy the convenience of road networks and provide feedback to road authorities. But the existence of work zones also post danger to them in high-speed driving situations.

(8) Road workers: road workers are employed by contractors and perform maintenance tasks in the highway work zones. Same as road users, their safety is also threatened in the process of maintenance work due to the high speed and inappropriate behaviors of road users.

(9) Insurance companies: driverless maintenance vehicles also need insurance as common vehicles. And due to its special technology and specific working conditions, new insurance policies are in demand for imputation when accidents take place.

Figure 4.1 provides a visualization of the stakeholder network. Based on the amount of connections between different stakeholders, it is reasonable to conclude that major stakeholders include The Ministry of Infrastructure and Water Management, Road authority, Vehicle authority, Contractors, Manufacturers, Research Institutions, Road Users and Road Workers. Hence, the interviewees were selected from these parties for insightful inputs.
Figure 4.1 Stakeholder Network
As listed in Table 4.1, totally 20 interviewees were invited to participate in a one-hour interview to provide their opinions of stakeholder involvement and driverless maintenance scenarios based on the Appendix B. The composition of interviewees is demonstrated in Figure 4.2 and interviewees from research institution, road authority and contractors were the major groups, accounting for 85%. The rest came from three parties, namely manufacturers, vehicle authority and The Ministry.

<table>
<thead>
<tr>
<th>Code</th>
<th>Stakeholder</th>
<th>Expertise</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Research Institution</td>
<td>Safety for self-driving vehicle and road machinery</td>
<td>TNO</td>
</tr>
<tr>
<td>A2</td>
<td>Automated driving</td>
<td></td>
<td>TU Delft T&amp;P</td>
</tr>
<tr>
<td>A3</td>
<td>Traffic safety</td>
<td></td>
<td>TU Delft T&amp;P</td>
</tr>
<tr>
<td>A4</td>
<td>Coordinator of IRIS_Project</td>
<td></td>
<td>VIAS</td>
</tr>
<tr>
<td>A5</td>
<td>Transport policy</td>
<td></td>
<td>TU Delft TBM</td>
</tr>
<tr>
<td>A6</td>
<td>Transport policy</td>
<td></td>
<td>TU Delft TBM</td>
</tr>
<tr>
<td>B1</td>
<td>Road Authority</td>
<td>Traffic safety, work zone expert</td>
<td>RWS</td>
</tr>
<tr>
<td>B2</td>
<td>Innovation and market Manager</td>
<td></td>
<td>RWS</td>
</tr>
<tr>
<td>B3</td>
<td>Traffic and road management</td>
<td></td>
<td>RWS</td>
</tr>
<tr>
<td>B4</td>
<td>Traffic safety, work zone expert</td>
<td></td>
<td>RWS</td>
</tr>
<tr>
<td>C1</td>
<td>Contractor</td>
<td>Road maintenance</td>
<td>BAM Infra</td>
</tr>
<tr>
<td>C2</td>
<td>Road maintenance</td>
<td></td>
<td>BAM Infra</td>
</tr>
<tr>
<td>C3</td>
<td>Large complex road building projects</td>
<td></td>
<td>Heijmans PMC</td>
</tr>
<tr>
<td>C4</td>
<td>Product manager of system integration and technology</td>
<td></td>
<td>Heijmans PMC</td>
</tr>
<tr>
<td>C5</td>
<td>Road maintenance</td>
<td></td>
<td>Volkerinfra</td>
</tr>
<tr>
<td>C6</td>
<td>Maintenance manager</td>
<td></td>
<td>Volkerinfra</td>
</tr>
<tr>
<td>C7</td>
<td>Road maintenance</td>
<td></td>
<td>BAM Infra</td>
</tr>
<tr>
<td>D1</td>
<td>Manufacturer</td>
<td>Automated driving</td>
<td>StreetScooter</td>
</tr>
<tr>
<td>E1</td>
<td>Vehicle Authority</td>
<td>Automated driving testing and legalization</td>
<td>RDW</td>
</tr>
<tr>
<td>F1</td>
<td>The Ministry of Infrastructure and Water Management</td>
<td>Automated driving</td>
<td>The Ministry</td>
</tr>
</tbody>
</table>
The knowledge and attitudes of the 20 interviewees regarding driverless maintenance were demonstrated in Figure 4.3.

It is demonstrated that 80% of the interviewees have heard of driverless maintenance before and 90% of the interviewees support the implementation of driverless maintenance to different degrees, in which the percentage of “strongly support” accounted for the largest part with 55%. It can be concluded that most interviewees owned certain knowledge of driverless maintenance and held positive attitudes towards its future implementation.

4.3. Stakeholder Analysis

In this research, the stakeholder matrix and power vs. interest grid were used to conduct the stakeholder analysis. In the former tool, the following attributes of stakeholders were collected and compared:

(1) **Interest:** this attribute reflects the interest of the stakeholder in the driverless maintenance plan and the advantages & disadvantages the stakeholder identifies in
the policy. The interest attribute helps to understand the concern and position of the stakeholder.

(2) **Alliances:** this attribute demonstrates that faced with the possibility of driverless maintenance application, which parties could share the same position with the stakeholder and would possibly align to make response to the driverless maintenance plan. The alliances attribute helps to group different stakeholders and identify potential organizational support or oppose.

(3) **Resources:** this attribute summarizes the amount of resources the stakeholder owns to promote the driverless maintenance plan and his ability to make use of them. The resources attribute helps to understand the importance of the stakeholder.

(4) **Power:** this attribute shows the ability of the stakeholder to affect the implementation of the driverless maintenance plan. The power attribute helps to understand the importance of the stakeholder as well.

Totally 20 interviews input data for parts of the stakeholder analysis, which were clarified from which interviews the conclusion was drawn. The process of transferring the information obtained in interviews to the results of stakeholder analysis was further explained in Appendix C. However, there were also parts of analytical thinking, which were not based on formal interviews, especially for the analysis of road users, road workers and insurance companies etc. For instance, the power of road users and road workers were expected to be low to medium in Table 4.2. But the power of the unions of road users or unions of road workers were uncertain and hard to evaluate. In addition, no relevant information was obtained from interviews. Hence, further research is necessary to investigate the power of different unions because no interview was conducted in this study.
### Table 4.2 Stakeholder Matrix

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Interest</th>
<th>Alliances</th>
<th>Resources</th>
<th>Power</th>
</tr>
</thead>
</table>
| Ministry of Infrastructure and Water Management | (1) Safety and efficiency of road work  
(2) Road condition  
(3) Maintenance cost  
(4) Workers’ health  
(5) Public affairs (Interview A6, B1) | Road authority, vehicle authority (Interview A6, B1) | Financial/Political resources (Interview A6, B1) | High |
| Road Authority | (1) Safety and efficiency of road work  
(2) Road condition  
(3) Maintenance cost  
(4) Workers’ health  
(5) Labour scarcity (Interview B1, B2, B3, B4) | The Ministry, vehicle authority, research institutions, contractors (Interview B1, B2, B3, B4) | Financial/Human/Political resources (Interview B1, B2, B3, B4) | High |
| Vehicle Authority | (1) Vehicle safety and legalization (Interview E1) | The Ministry, road authority, contractors, manufacturers (Interview E1) | Human resources (Interview E1) | High |
| Contractors | (1) Safety and efficiency of road work  
(2) Maintenance cost  
(3) Workers’ health  
(4) Labour scarcity (Interview C1-C7) | Road authority, vehicle authority, manufacturer, research institutions, insurance company (Interview C1-C7) | Financial/Human resources (Interview C1-C7) | Low - Medium |
| Manufacturers | (1) New market  
(2) Safety and efficiency of road work (Interview D1) | Research institution, contractors, vehicle authority, insurance company (Interview D1) | Financial/Human/Technical resources (Interview D1) | Low - Medium |
| Research Institutions | (1) Knowledge flow  
| Road Users | (1) Safety and efficiency of road work | Road users | - | Low - Medium |
| Road Workers | (1) Safety and efficiency of road work  
(2) Workers’ health  
(3) Salary | Road workers | - | Low - Medium |
| Insurance Company | (1) New market  
(2) Safety and efficiency of road work | Contractors, manufacturers | - | Low |

#### 4.3.1. Interest

(1) **The Ministry of Infrastructure and Water Management**: in the case of implementing driverless maintenance, the major interest of The Ministry includes (1) improving the
safety and efficiency of road work; (2) improving road conditions; (3) reducing road maintenance cost; (4) improving road workers’ safety and (5) dealing with public feedback regarding driverless maintenance. Based on interviews A6 and B1, from the perspective of The Ministry, driverless maintenance is likely to achieve (1)(2)(3)(4) but increase the pressure of (5). For instance, once the pilot test of driverless maintenance vehicle suffers technical failures, it is The Ministry who has to be criticized by the public.

(2) Road authority: the interest of road authority is quite similar to that of The Ministry in driverless maintenance case, including (1) improving the safety and efficiency of road work; (2) improving road conditions; (3) reducing road maintenance cost; (4) improving road workers’ health and (5) improving labor scarcity. Based on interviews B1-B4, candidates from Rijkswaterstaat came to a consensus that driverless maintenance has the potential to be successful in (1)-(5). By setting free road workers out of dangerous highway work zones and increasing the frequency of maintenance, driverless maintenance could achieve both safe and efficient working and better road conditions. On the other hand, the labor cost is saved and workers don’t have to endure the high stress from working environments, which is better for their health. Considering the demographic structure of the Netherlands (In 2019, 6.9 million of the 13.7 million adults will be older than 50 years (CBS, 2014)), driverless maintenance is also capable of relieving the urgent labor shortage problem. As for the disadvantages, answers such as short-term job loss and technical failures are collected from interviews with experts from Rijkswaterstaat.

(3) Vehicle authority: based on interview E1, the interest of vehicle authority is relative simple, including the safety and legalization of driverless maintenance vehicles. It is necessary to apply for authorization from the vehicle authority for driverless maintenance vehicles when a pilot test is about to take place.

(4) Contractors: the interest of contractors was identified from interviews C1-C7 as following: (1) improving the safety and efficiency of road work; (2) reducing road maintenance cost; (3) improving road workers’ health and (4) improving labor scarcity. It is clear that there is a full overlap between the interest of contractors with that of road authorities. However, from interviews with contractors, a list of disadvantages was collected. Apart from job loss and technical failures, contractors expressed stronger concern about unknown and huge investments and time-consuming development process.

(5) Manufacturers: the major interest for manufacturers was obtained based on interview D1, namely (1) entering into a new market and (2) improving the safety and efficiency of road work. Driverless maintenance vehicles, as a new type of product, are attractive to manufacturers when the demand is high. In addition, driverless maintenance provides a very specific user cases for automated driving technology, which reduces the technical complexity. Due to the possibility of improving maintenance safety and efficiency, there is potential demand waiting for manufacturers. But similarly, manufacturers have doubts as well about the cost of
research and production of driverless maintenance vehicles, which is expected to be high. Hence, it is unknown whether they can achieve cost benefit balance.

(6) **Research institutions**: the major interest of research institutions is the knowledge flow and education, based on interviews A1-A6. It is an opportunity for research institutions to provide knowledge, technology and resources to market parties to develop driverless maintenance vehicles. And the road tests of products could enlarge the database of research institutions in turn. When the technology is mature, it is also possible to develop driverless-vehicle-based maintenance strategy and add it to the education of students, which generate extra academic values. When it comes to possible advantages, technical failures and high cost are also two major concerns.

(7) **Road users**: road users care (1) the safety and efficiency of road work and (2) road conditions. If driverless maintenance could improve the safety and efficiency of road work, then the consequence of accidents and possible delay caused by congestion are expected to be reduced, which is beneficial to the road users. There is a union of road users, called ANWB. Even though it is not a deciding party in the case of driverless maintenance implementation, once the interest of road users is damaged due to technical failures of driverless maintenance, the organization will turn against the plan.

(8) **Road workers**: road workers care (1) the safety and efficiency of road work and (2) workers’ health and (3) salary. Driverless maintenance could satisfy the requirement of (1) and (2). However, it is also a threat to (3). The labor union might oppose driverless maintenance due to this reason. But in the long term, road workers can find safer jobs, which is better for both their physical and mental health.

(9) **Insurance company**: the interest of insurance company includes (1) entering into a new market and (2) the safety and efficiency of road work. Insurance companies can enter into contract with driverless maintenance vehicle users and owners, which is a new business for them. The safety and efficiency of road work will be an important factor for insurance companies to decide the premium and related policy.

### 4.3.2. Alliances

(1) **The Ministry of Infrastructure and Water Management**: The Ministry depends on road authorities and vehicle authorities to implement related policy for driverless maintenance, based on interview B4. In turn, by conducting pilot tests and collecting feedback from road users, road authorities and vehicle authorities could discuss about the improvements in policy making, based on interviews B1 and E1. Hence, these three parties form alliances at the political level.

(2) **Road authority**: apart from the collaboration with The Ministry and vehicle authorities, road authorities are likely to participate in cooperation with market parties (contractors and manufacturers) and research institutions as well, in order to promote
the development of driverless maintenance. For instance, from interviews with Rijkswaterstaat's members, it is known that in the organization there is an innovation cluster, which would discuss with market parties and research institutions about innovations and even deliver some research budgets by launching research projects. In addition to innovative development, road authorities also rely on contractors to conduct maintenance tasks, which leads to a more direct and stable alliance (Interviews B1-B4).

(3) **Vehicle authority:** similar to road authorities, vehicle authorities have closed contact with market parties. In driverless maintenance context, vehicle authorities should make sure the driverless maintenance vehicles are authorized and permitted to work on roads. Frequent communications between these parties are beneficial to testing and improving driverless maintenance vehicles (Interview E1).

(4) **Contractors:** as mentioned above, contractors are likely to align with government parties when exploring driverless maintenance development. As a market party, it is possible for contractors to enter cooperation with manufacturers and research institutions to form a technical alliance, which may put the driverless maintenance technology to the ground. There is also an association for contractors called Bouwend Nederland (Dutch Builders), in which contractors will discuss the development trend of industry and market and promote the flow of knowledge and technology. Another possible partner in driverless maintenance implementation could be the insurance company, which could help reduce the risk of implementation of driverless maintenance vehicles (Interviews C1-C7).

(5) **Manufacturers:** as another market party, manufacturers also need support from government parties because of the high risk of innovations. As the producer and seller of driverless maintenance vehicles, manufacturers could partner with research institutions in terms of technical development and align with contractors from the aspect of market entry. No surprisingly, insurance companies could engage to help reduce the risks (Interview D1).

(6) **Research institutions:** it is common for research institutions to cooperate with road authorities, contractors and manufacturers to conduct some research projects. These kinds of alliances are more project-based (Interviews A1-A6).

(7) **Road users:** road users form an association named ANWB in the Netherlands. This organization could express and protect the interest of road users when it feels that driverless maintenance makes road maintenance worse.

(8) **Road workers:** labor unions represent the interest of road workers.

(9) **Insurance company:** insurance companies will make dedicated policy for driverless maintenance vehicles and could sign contract with manufacturers and contractors. The participation of insurance companies could make driverless maintenance more mature in the commercial sense.
4.3.3. Resources

(1) **The Ministry of Infrastructure and Water Management:** The Ministry owns necessary political resources to implement driverless maintenance. The application of automated driving technology on highways definitely requires approval from the government. Furthermore, it is possible that dedicated policy would be designed for driverless maintenance vehicles. Once the development of driverless maintenance obtains the support from national government, The Ministry might also deliver financial resources for research projects (Interviews B1, B4 and E1).

(2) **Road authority:** as part of the government, road authorities have political and financial resources for driverless maintenance development. Take Rijkswaterstaat as an example, it receives an annual budget of 6 billion euro, part of which could be used for driverless maintenance researches. In addition, Rijkswaterstaat has the authority to change related regulations about road maintenance. It is also possible that a dedicated working team could be organized to follow and promote the development of driverless maintenance, as members from Rijkswaterstaat stated in interviews. Hence, road authorities could provide political, financial and human resources. According to the results of interviews, financial resources in Rijkswaterstaat could be relative easily available and mobilized while it is converse for human resources (Interviews B1-B4).

(3) **Vehicle authority:** similar to road authorities, vehicle authorities also hold political and human resources for driverless maintenance development by organizing teams to make regulations and issue licenses for driverless maintenance vehicles. However, unlike road authorities, which are responsible for road maintenance, vehicle authorities have less interest in driverless maintenance and deliver no financial resources to it (Interview E1).

(4) **Contractors:** contractors have financial and human resources for innovations. However, as a market party, contractors are faced with more restrictions from market size and laws. And they care more about the return of investments. Therefore, they are hesitant to mobilize these resources to promote driverless maintenance (Interviews C1-C7).

(5) **Manufacturers:** as another market party, besides financial and human resources, manufacturers own technical resources as well for driverless maintenance development. The core technology of driverless maintenance vehicles is expected to be provided by manufacturers. From interviews, even though these resources within companies could be quickly mobilized, manufacturers should take into account market demand and laws before entering this new market (Interview D1).

(6) **Research institutions:** research institutions have technical, human and financial resources to support driverless maintenance researches. Technical resources may come from the outcome of previous researches. Human resources may include professors, researchers and PhD students etc. Financial resources may stem from
budgets from national government or European institutions and market parties. In this sense, human resources in research institutions depend on financial resources, which rely on support from political or market parties, therefore more external than internal (Interviews A1-A6).

4.3.4. Power

(1) **The Ministry of Infrastructure and Water Management:** whether driverless maintenance could be implemented and how it would be implemented depends on policy and regulations from The Ministry to a large extent. It is reasonable that The Ministry plays a high powerful role in the implementation of driverless maintenance (Interviews B1, B4 and E1).

(2) **Road authority:** road authorities are responsible for highway maintenance. More than half of the interviewees stated that road authorities should take initiatives to promote driverless maintenance by making driverless maintenance legal and encourage research by delivering budgets and making compensations in the contract. The leading role of road authorities in the eye of many interviewees proved their high power in the implementation of driverless maintenance (Interviews B1-B4).

(3) **Vehicle authority:** as mentioned before, the pilot test of driverless maintenance vehicles requires approval from vehicle authorities. Once vehicle authorities consider the technology as unsafe or unreliable, the application will be rejected. In this sense, vehicle authorities hold high power in the implementation of driverless maintenance (Interview E1).

(4) **Contractors:** contractors are the party who is going to use driverless maintenance vehicles to perform maintenance tasks. They will develop a business case and make cost benefit analysis to examine the financial feasibility. However, they lack technical resources for driverless maintenance innovations and they tend to rely on proved technology, which reduces their impact on the implementation of driverless maintenance. In addition, as a market party, decision making in the organizations is depending on the policy and regulations to a large extent. Hence, it is concluded that the power of contractors ranges from medium to low degree (Interviews C1-C7).

(5) **Manufacturers:** manufacturers own financial, human and technical resources, which reflects their potential strong contributions to the development of technology. However, they are not sure if driverless maintenance products would be accepted by the market. Considering the large investments on technical researches, manufacturers are more cautious and desire for support from political levels. Otherwise they need to bear huge risks due to uncertain return period, which could be out of their control. Hence, it is concluded that the power of manufacturers ranges from medium to low degree as well (Interview D1).

(6) **Research institution:** Even though research institutions have required financial, human and technical resources for driverless maintenance development, these resources, as
mentioned before, are mainly external and cannot be so quickly mobilized as those of manufacturers. But once project-based cooperation comes into being between research institutions and political or market parties, knowledge flow will definitely cast positive influence on improvements of technology. Hence, the power of research institutions is regards as between low and medium degree (Interviews A1-A6).

(7) Road users: road users are expected to react to the outcome of studies rather than take actions in the development because they don’t have any necessary resources. None of the interviewees believed road users will stand against driverless maintenance. Instead, they will welcome this innovation thanks to its potential to improve road work safety and road conditions. But once technical failures take place, the union of road users, such as ANWB, would stand against the implementation of driverless maintenance. Hence, the power of road users is, therefore, considered as low to medium.

(8) Road workers: road workers will be replaced by driverless maintenance vehicles. Most interviewees held the view that even if in the short term the interest of road workers would be damaged in the implementation of driverless maintenance, in the long run they will find safer and healthier jobs. In addition, they don’t have necessary resources either and they are required to make themselves more flexible and sustainable in job markets. However, the union of road workers does have some power to protect the interest of road workers when driverless maintenance replaces them. Hence, the power of road workers is, therefore, considered as low to medium as well.

(9) Insurance company: insurance companies have no resources to affect the implementation of driverless maintenance, either. They also won’t take initiatives to participate in the market. They seem more to be an outsider and could be invited to help market parties manage possible risks. Hence, the power of insurance companies is also deemed to be low.

In the power vs. interest grid, the interest attribute and the power attribute were combined to measure the criticality of various stakeholders. Based on the analysis above, these stakeholders were arranged into different regions, as demonstrated in Figure 4.4 Power vs. Interest Grid.
High Power & Interest
The Ministry and road authorities are located in the high power & interest area, which reflects their high criticality among all stakeholders. Therefore, they should be closely managed. To be more specific, according to the level of involvement described by Byson (2004), The Ministry is supposed to empower, which means what it decides will be implemented, and road authorities is supposed to collaborate, which means their advice and recommendations will be incorporated to the maximum extent possible. The difference exists between the management strategies towards The Ministry and road authorities because the former party is the one who makes policy and the latter plays the role to implement the policy and is responsible for discovering problems and sending feedback.

High Power & Low Interest
Vehicle authorities are set in the high power & low interest region. In the implementation of driverless maintenance, they should be kept satisfied. Otherwise the application for pilot tests would be rejected. According to Byson’s description, vehicle authorities is ought to be involved, which means they become a working party in the implementation of driverless maintenance so that their concerns could be considered and reflected and feedback could be provided to demonstrate how their inputs influenced the decision making. For instance, vehicle authorities would provide an assessment of driverless maintenance vehicles to explain why the pilot test is rejected if it really happens. This assessment is considered beneficial to the improvements.

High Interest & Low Power
Contractors and manufacturers lie in the high interest & low power part and should be kept informed. They are actually close to the high power and interest region because they could perform medium power in some issues. Therefore, based on Byson, they should be involved and even collaborated in the implementation of driverless maintenance. In terms of commercial and technical decision making, their opinions should be put more emphasis.
Low Power & Interest
Research institutions, road users, road workers and insurance companies are laid in the low power and interest corner and their reactions should be monitored. Two different involvement levels are identified for research institutions and the rest stakeholders because research institutions were considered to be able to generate medium power on the implementation of driverless maintenance once they enter into cooperation with other stakeholders and gain resources support. Hence, based on Byson, they should be involved or consulted, which means even if they are not a working member, they will still be informed and their opinions will be considered and feedback will be provided. The rest three parties could be just informed due to their low criticality. But it is better to involve the unions of road users and road workers so that the potential conflicts with them could be instantly observed and tackled.

4.4. Stakeholder Engagement
In the interviews, three kinds of development routes of driverless maintenance were discussed, depending on which party should take the initiatives to promote the development. As Figure 4.5 demonstrates, different answers were provided, which can be categorized into three groups, namely government leading development (The Ministry and Rijkswaterstaat), market leading development (contractors and manufacturers) and joint efforts. 52% of the interviewees believed government should play the leading role to promote driverless maintenance. 39% of the interviewees thought market parties were supposed to take the initiatives, in which 77% of the candidates considered manufacturers as the leading role while the rest 23% relied on contractors. 9% of the interviewees stated that joint efforts between the government and market parties were necessary to be the solution.

![Figure 4.5 Leading Party in Driverless Maintenance Development](image)

4.4.1. Government Leading Development
The Ministry and road authorities were expected to play the leading role in promoting driverless maintenance in this development model. The reason is that without permission and dedicated regulations regarding the application of driverless maintenance vehicles,
market parties are hesitated to make investments, especially when the investments are predicted to be huge in driverless maintenance researches. Apart from dedicated policy, in order to promote driverless maintenance, interviewees from market parties also pointed out that they hoped road authorities could make some adjustments in the contract:

1. **Clear requirements**: even though interviewees (Interviews B1-B4) agreed that road authorities welcome innovations, market parties (Interviews C1-C7) will not focus on driverless maintenance unless it states clearly in the bid book or contract that driverless maintenance is a desired maintenance plan.

2. **Cost compensation**: since driverless maintenance serves as an innovation to improve the road work safety and it requires huge investments in the beginning, it is reasonable to ask for cost reduction in the tendering phase when compared to other tenders so that market parties could gain the motivation to develop the technology (Interviews C1-C7).

3. **Contract extension**: currently Rijkswaterstaat enters into a 5-year contract with contractors. If the contract could be extended to 10 years, contractors would feel more attracted to make investments on innovations (Interviews C1-C7).

However, this model also faces some problems, which could hinder the development:

1. **Political risks**: government institutions were ought to be responsible for any technical failures. Currently it is not legal to apply driverless maintenance vehicles and the pilot test is just an exemption. Dedicated policy and regulations will always be issued later based on lots of experiment data (Interviews A6, B3 and E1).

2. **Bureaucracy**: when government institutions control the development of driverless maintenance, the process will be more time consuming due to bureaucracy. Considering the huge initial investments, longer development process leads to longer return period (Interviews C1 and C2).

3. **Functional contract**: road authorities usually enter into a functional contract with contractors, which means they only specify the expected outcome in the contract and set no restrictions to the way of doing maintenance. But contractors tend to apply cheaper plan rather than keep improving working safety, therefore, driverless maintenance is not an ideal choice (Interview B1).

4. **Subcontractors**: as mentioned above, contractors could be conservative and lack motivations to develop driverless maintenance. Besides, based on the experience of Rijkswaterstaat’s experts, the contractor usually manages several subcontractors, who tend to underestimate the risks of road maintenance. Hence, they are less willing to make contributions to driverless maintenance development (Interview B1).

In spite of these problems, more than half of the interviewees thought government leading development could be the solution because the implementation of driverless maintenance
need deal with lots of legal issues and requires a large amount of investments, which exceeds the ability of market parties.

4.4.2. Market Leading Development

Interviewees who supported market leading development stated that driverless maintenance was a technology issue, which was not a core business of road authorities. Hence, market parties, especially manufacturers should take the initiatives to develop driverless maintenance vehicles. After they prove driverless maintenance vehicles to be safe and reliable, government institutions will be persuaded to make dedicated policy and regulations. However, from the interviews, several requirements must be satisfied so that market parties are willing to play the leading role:

1. **Market size:** from the perspective of manufacturers in the interview, the market of driverless maintenance products is rather small unless these vehicles are allowed to be sold and applied in the European market. However, in that case, government institutions of different European countries should be involved to discuss the feasibility, which is far more complicated (Interviews C3, C4 and D1).

2. **Business case:** it is necessary for market parties to develop a business case for the implementation of driverless maintenance vehicles. They need to take into account in what situations are these vehicles supposed to be applied and in the whole life cycle of the implementation how cost and benefit will change. It is important that market parties could develop their business models and earn profits within the acceptable period (Interviews C1-C7 and D1).

3. **Competition:** based on the experience of the interviewee from vehicle authorities, manufacturers would sometimes invest on innovations merely because competitors do the same thing. They want to follow the trend in case of falling behind when the market is growing. Take automated driving vehicles as an example, even if the market is not that large and these vehicles are not completely legal, manufacturers are still willing to compete with each other for innovations (Interview E1).

4. **Political support:** in the market leading model, the biggest concern of manufacturers comes from the uncertainty of market demand. Even though government institutions can only make dedicated policy and regulations for driverless maintenance vehicles based on a number of successful pilot tests, they could still provide some political supports for market parties by promising them an amount of guarantee orders so that manufacturers feel safer and motivated to invest on technology (Interview D1).

Same as government leading development, it is inevitable that this model is also accompanied with some problems:

1. **Lack of motivation:** the major concern of market parties is that if their involvement in the implementation of driverless maintenance could generate profits for them. As mentioned before, the market could be rather small and the return period could be
longer than expectation. Without the support from government institutions, market parties would be hesitated to take the initiatives (Interview C1-C7 and D1).

(2) **Legal risks:** the implementation of driverless maintenance involved lots of legal issues, as many interviewees pointed out. Apart from the uncertainty of market demand, market parties should also deal with large legal risks such as possible rejections from vehicle authorities in the application of pilot tests and potential disapproval from road authorities in the road maintenance contract due to technical failures (Interview C1-C7 and D1).

(3) **Long process:** as mentioned before, even the pilot test of driverless vehicles is not legal in the Netherlands. Vehicle authorities only offer an exemption after a systematic assessment of the vehicles. The vehicles are allowed to be tested in the track of road authorities in Lelystad first and after a successful pilot they are permitted to be tested on real physical roads, in this case real physical work zones, which are determined before. This process could last several months and even one year if market parties are not well prepared. In addition, even if the vehicles pass the whole process successfully, it is still illegal to apply them directly on work zones. Whenever the vehicles are about to be used, they need to go through this whole process all over again but in a shorter duration (Interview E1).

The reasons why some interviewees supported market leading development model include the technical resources and commercial considerations of market parties. The former makes it possible to produce driverless maintenance vehicles and the latter examines the commercial perspective of the products. If driverless maintenance always need rely on the support or subsidies of government institutions rather than be developed into a mature business case, it will not be sustainable for all stakeholders.

**4.4.3. Joint Efforts**

Due to the difficulties identified in the previous two development models, a group of interviewees held the view that joint efforts between government institutions and market parties were necessary. In practical, both parties could have discussions about the development of driverless maintenance or even organize study tours to other countries in order to learn their experience. Road authorities could also launch research projects and deliver budgets to market parties for technical development. As for legal issues, frequent feedback based on research and tests is expected to be sent to government institutions, serving as important references for policy making.

However, it was not easy to gather government institutions and market parties to a table, based on inputs from interviewees. The original idea of developing driverless maintenance is to improve the safety of road maintenance. Hence, if these stakeholders could enter into cooperation is depending on their safety culture to a large extent, as explained in Section 1.2. Based on interview B1, it was concluded that Rijkswaterstaat stayed at the level of calculative safety culture and tried to move forward towards proactive safety culture. The safety culture ladder of Rijkswaterstaat could be found in Appendix. In this case, driverless
maintenance is a good plan to support the improvement to higher level of safety culture. However, based on interviews with different contractors (Interviews C1-C7), some of them stay at the same level as Rijkswaterstaat while others are located at the second level or even lower. It is crucial that road authorities could cooperate with the contractors, who are at the same safety culture level and tend to move upwards, or could narrow the gap between contractors before making joint efforts to implement driverless maintenance.

According to interviewee D1, driverless maintenance could not only improve work safety but also generate a large database, which was helpful for developing accurate maintenance, preventive maintenance and the automated driving technology itself because the road condition and the performance of driverless system could be recorded in the database. In addition, each driverless maintenance could include the traffic data during the working process so that the traffic efficiency and safety situation could be analyzed. Then safety measures can be taken in advance, leading to a proactive safety culture. Hence, the implementation of driverless maintenance matches the goal of Rijkswaterstaat to move to the higher safety level.

4.5. Summary

Above all, 9 stakeholders were identified regarding the implementation of driverless maintenance, including The Ministry of Infrastructure and Water Management, road authority, vehicle authority, contractors, manufacturers, research institutions, road users, road workers and insurance companies. Based on 20 interviews with these stakeholders, the interest, alliances, resources and power of different parties were analyzed with the tools of Stakeholder Matrix and Power-Interest Grid.

It is concluded that The Ministry of Infrastructure and Water Management and road authority have both high power and high interest. In particular, The Ministry owns financial and political resources and align with other governmental parties, such as road authority and vehicle authority. The involvement strategy for The Ministry is to empower. Road authority owns financial, human and political resources and align with both governmental parties and market parties. The involvement strategy is to collaborate. Vehicle authority has high power but low interest. This party also align with both governmental and market parties but could only provide human resources. The strategy is to be involved. Contractors and Manufacturers have high interest but relative low power. Contractors owns financial and human resources while manufacturers own one more technical resource. The involvement strategy for both parties is to be involved and to collaborate. The rest parties, including research institutions, road users, road workers and insurance company, have both low interest and relative low power. The involvement strategy for research institutions is to be involved or consulted and the involvement strategy for the unions of road workers and road users is to involve them. It is enough merely to inform the insurance company of the development.

Based on the interviews, three types of stakeholder engagement plan were summarized, including government leading development, market leading development and joint efforts between government and market. When government takes the initiatives to develop
driverless maintenance, clear requirements, cost compensation and contract extension were believed to be necessary conditions. In addition, problems generated by political risks, bureaucracy, functional contract and subcontractors were likely to hinder government leading development. When market parties take the initiatives to develop driverless maintenance, market size, business case, competition and political support were the major concerns of them. However, lack of motivation, legal risks and long process were thought to affect this development negatively. Last but not least, joint efforts between government and market were an ideal option to deal with the problems in the previous two development models. But it is important that both parties are located in the same safety culture level and share the same goal to move forward to higher level because implementing driverless maintenance is such a plan to improve the current calculative safety culture of Rijkswaterstaat to proactive safety culture.
5. Driverless Maintenance Simulation
In order to investigate the traffic impact of driverless maintenance, microscopic simulation was utilized for investigating driverless maintenance scenarios. Based on the literature review about traffic simulation in highway work zones, important factors which influence traffic safety and efficiency in highway work zones were summarized. Following this, the interview design was discussed, in which specific driverless maintenance scenarios were discussed with the interviewees. Based on the constructed scenarios, simulations in VISSIM helped to understand the impact on traffic safety and efficiency of driverless maintenance.

5.1. Traffic Simulation of Highway Construction Zones

Traffic simulation is a common method for investigating traffic problems. It applies computer technology to analyze targeted variables and their relationship to traffic flow. It also provides a visualized traffic environment, therefore saves lots of manpower resources and time (Tang & Chen, 2009).

In this study, the software VISSIM was selected to conduct the simulation not only due to its simplicity but also its simulation of vehicle lane change, vehicle following and waiting behaviors etc. (Ding et al, 2013), which are related to traffic safety and efficiency. The simulation was based on the built scenarios in the interviews. By modelling the working conditions and other traffic environments of driverless maintenance vehicles, the research investigated the traffic impacts after implementing driverless maintenance, including the influence on traffic safety and traffic efficiency. The simulation provided some quantitative results regarding traffic impact analysis of driverless maintenance.

There are three blocks interacting in a VISSIM simulation, including infrastructure, traffic and control, as shown in Figure 5.1. A traffic scenario could only be simulated with these parameters determined. In addition, there are some models regarding driver behaviors, such as car following model and lateral movements model, which should be taken into account in the simulation. After a simulation is set up, calibration and validation are usually conducted by collecting real data.

![Figure 5.1 Four Building Blocks in VISSIM (Fellendorf & Vortisch, 2010)](image-url)
Traffic simulations of highway work zones in VISSIM also followed the requirements mentioned above. As Zhang et al. (2016) simulated a temporary work zone in XuChang-WeiShi Highway (China), which is a two-lane motorway with a design speed of 120 km/h and a speed limit of 60 km/h in the work zone. Real traffic data was input to determine the parameters and the desired speed distribution was calibrated. Another simulation dealt with a highway work zone in the City of Covington (Park & Qi, 2006), in which field data was also collected for initial simulation. And the calibration focused on both desired speed distribution and car following and lane changing models. In this chapter, field traffic flow data was also input for simulations.

5.1.1. Traffic Efficiency in Highway Construction Zones Simulation

Great efforts have been devoted to traffic simulation in work zone in terms of traffic efficiency, Weng & Meng (2012) identified 16 key factors influencing work zone capacity, as Figure 5.2 demonstrates, including work zone configurations (number of open lanes, number of closed lanes, lane closure location, work zone grade, work zone length, work zone speed), work zone characteristics (work zone intensity, work zone duration, work time), roadway conditions (road type, lane width, ramp, state/city), environmental conditions (weather condition) and other factors (heavy vehicle percentage, driver composition).

![Figure 5.2 Factors Influencing Work Zone Capacity (Weng & Meng, 2012)](image)

Most simulation studies explored the impact upon traffic efficiency by changing certain variables mentioned above, especially those from work zone configurations and work zone characteristics. Radwan et al. (2011) explored the impact upon throughputs in work zones when Dynamic Lane Merge (DLM) system and Variable Speed Limit (VSL) system were applied. The DLM system, including dynamic early merge and dynamic late merge, functioned as demonstrating a dynamic “NO-PASSING” zone so that drivers could merge
into open lanes before reaching the taper of work zone. The VSL system made the speed limit changed according to road conditions. By changing the arrangements of DLM and VSL, this research actually adjusted the key factors lane closure location and work zone speed. It turned out that when traffic volume was low or medium (Vehicles per hour: V500, V1000, V1500), no significant difference existed when DLM or VSL was implemented, while in high volume levels (V2000, V2500), late DLM with or without VSL both showed higher mean throughputs and the integration of DLM and VSL demonstrated better performance in traffic mobility. Another research (Ding et al., 2013) investigated the impact upon traffic mobility by changing transition area length of work zone and speed limit value in VISSIM. It was concluded that the traffic mobility in work zone was inversely proportional to the length of transition area while proportional to speed limit value, which means with shorter transition area length and higher speed limit value, the travel time became less. In addition, the speed limit value generated greater influence. Zhu (2015) also found out work zone capacity decreased with longer work zone length and increased with higher speed limit in a two-lane highway work zone section. Hence, speed limit in work zone, work zone length and lane closure location affected the work zone efficiency the most and they could be input in the simulation model.

5.1.2. Traffic Safety in Highway Construction Zones Simulation

As for traffic safety, existing studies selected speed variance as an indicator to reflect the degree of unsafety. Zaidi et al. (2013) focused on DLM and VSL as well, in which similar traffic scenarios were constructed as Radwan et al. (2011). The simulation revealed that in low or medium traffic volume levels (V500, V1000, V1500), DLM performed better in reducing speed variance. However, when traffic volume became higher (V2000, V2500), VSL demonstrated significantly better performance in decreasing speed variance. Besides traffic mobility, Ding et al. (2013) examined the impact upon traffic safety of transition area length and speed limit value as well. The results stated that the traffic safety in work zone was linear with both the length of transition area (another reflection of lane closure location) and the value of speed limit. With longer transition area length and higher speed limit value, the speed variance could be reduced.

Apart from the studies above simulating static work zones, Edara et al. (2017) also conducted a simulation of dynamic work zone situation, in which two slow-moving trucks remained on the right lane of road network with a distance of 250 ft. The downstream truck served as the working vehicle and the upstream one was regarded as the shadow vehicle, which is a common dynamic work zone setup according to MUTCD. In the research, the number of two kinds of conflicts, namely the rear end and lane change conflicts, was selected to display the traffic safety degree. It turned out that in low traffic volume level (V350), few conflicts took place, while in medium volume levels (V700, V1000, V1400), the number of conflicts demonstrated a near-linear increase as the work duration increased and in high volume level (V1800), this relationship is non-linear. Recommendations came from this simulation study that the dynamic maintenance work could be conducted for a short duration when traffic volume is high or for a longer duration when traffic volume is lower.
Hence, speed limit in work zone, work zone duration, lane closure location are also key factors influencing traffic safety in work zones and among the parameters which could be simulated in VISSIM.

5.2. Driverless Maintenance Scenarios Building

The introduction of driverless maintenance in highway work zones is a practical issue, which involves a large group of stakeholders. Since the researcher is not the core of driverless maintenance development, it is crucial to understand the lived experience of the parties involved and the meaning they make of that experience (Seidman, 2006). The interest in stakeholders’ stories and inputs is the root of interview technique. In addition, interviews with stakeholders were considered as a useful technique to identify the needs of users and establish requirements (Cohene & Easterbrook, 2005). In this research, the purpose of interviews was to understand the stakeholders’ opinions regarding when implementing driverless maintenance and to imagine the future driverless maintenance applications with stakeholders together.

5.2.1. Interview Design

The Part A of the interview protocol was explained in Section 4.1. This section discussed the design of Part B. In Part B, interviewees were invited to construct driverless maintenance scenarios for traffic impact analysis and cost-benefit analysis in the following stage. The so-called driverless maintenance scenarios were certain maintenance activities, which were conducted by driverless vehicles in specific working conditions. It was concluded in Section 3.2 that the following 7 maintenance activities could be widely developed towards driverless maintenance.

<table>
<thead>
<tr>
<th>Code</th>
<th>Maintenance Activity</th>
<th>Working Conditions</th>
<th>Working Area</th>
<th>Vehicle &amp; Worker</th>
<th>Protection Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mowing</td>
<td></td>
<td>On the shoulder</td>
<td>The vehicle doesn’t stop and workers don’t leave the vehicle</td>
<td>Not a must</td>
</tr>
<tr>
<td>2</td>
<td>Marking Painting</td>
<td></td>
<td>On lanes and shoulder</td>
<td>The vehicle doesn’t stop and workers don’t leave the vehicle</td>
<td>Necessary when working on lanes</td>
</tr>
<tr>
<td>3</td>
<td>Litter Removal (Asphalt Cleaning)</td>
<td></td>
<td>On lanes and shoulder</td>
<td>The vehicle doesn’t stop and workers don’t leave the vehicle</td>
<td>Necessary when working on lanes</td>
</tr>
<tr>
<td>4</td>
<td>Pothole Repairs</td>
<td></td>
<td>On lanes and shoulder</td>
<td>The vehicle will stop and workers don’t leave the vehicle</td>
<td>Necessary when working on lanes</td>
</tr>
<tr>
<td>5</td>
<td>Illumination Cleaning</td>
<td></td>
<td>On the shoulder</td>
<td>The vehicle doesn’t stop and workers don’t leave the vehicle</td>
<td>Not a must</td>
</tr>
<tr>
<td>6</td>
<td>Assistance to Traffic (Shadow Vehicle)</td>
<td></td>
<td>Depending on the work vehicle</td>
<td>The vehicle will stop and workers don’t leave the vehicle</td>
<td>\</td>
</tr>
<tr>
<td>7</td>
<td>Sealing Cracks and Joints</td>
<td></td>
<td>On lanes and shoulder</td>
<td>The vehicle will stop and workers don’t leave the vehicle</td>
<td>Necessary when working on lanes</td>
</tr>
</tbody>
</table>
In Section 2.1, it was mentioned that in CROW (2017) there were three types of dynamic work zones, namely the work zone occupying only the shoulder, the one occupying both the right most lane and the shoulder and the one occupying multiple lanes (working on the intermediate lane). This research investigated the traffic impact of driverless maintenance in the former two types of work zones. Hence, a motorway with two lanes and a shoulder was simulated and the driverless maintenance scenarios base was supposed to be further narrowed. As it is shown in Table 5.1, some maintenance activities share the same working conditions. Therefore, as demonstrated in Figure 5.3, three typical kinds of activities were selected for scenarios building, namely mowing, marking painting and pothole repairs due to their different working conditions (blue parts in Table 5.1).

![Figure 5.3 Driverless Maintenance Scenarios Building](image)

In the interviews, these three activities done by driverless maintenance vehicles in a two-lane motorway were described for the interviewees and the interviewees were asked to describe detailed working conditions, such as speed limit, working period etc., for each activity and to predict possible impacts on driver behaviors, such as lane changing, following mode etc. Based on this input from the interviewees, traffic simulation was conducted for the three driverless maintenance scenarios.

### 5.2.2. Scenarios Building

In the interviews, maintenance vehicles for mowing, marking painting and pothole repairs were assumed to be driverless. Possible changes would take place in terms of several working condition parameters and driver behaviors, including working period, working speed, speed limit, signs and protection vehicles etc. Based on the answers, those changes with the highest frequency were integrated to create scenarios.

Take mowing as an example, Figure 5.4 shows the results of the judgments from interviewees about the change of parameters in driverless maintenance situation.
As for working speed, in total 20 answers were received, in which the choice “increase” tops all answers with 10 interviewees, followed by the answer “remain the same” with 6 interviewees. Hence, the most possible change in working speed was determined to be increasing. Similarly, more frequent nighttime maintenance was assumed to be the most possible change in working period. In terms of speed limit and impact on driver behaviors, it was observed that the most frequent answers were “remain the same”. In this case, the second popular answer was selected if the frequency reaches half of the frequency of the most popular one. The reason why this adjustment was made was that it was difficult to predict the changes in driverless maintenance situations and most interviewees may be not aware of possible changes because of uncertainty. But if certain changes were agreed by a group of people and the amount of the supporters reached the half of the group members, who thought things would remain the same, it is reasonable to take the changes into account. Hence, in terms of speed limit, the answer “increase” was accepted but in the “impact on driver behaviors”, “slow down in the beginning” and “change lanes later” were ignored. The last parameter is “special signs”, in which 15 out of 20 interviewees believed it was not necessary to set special signs for road users to make them realize the maintenance is driverless. In conclusion, driverless mowing is the first scenario, compared to the current situation, with higher working speed and speed limit, more frequent nighttime maintenance, no special signs and no change in terms of the impact on driver behaviors.
Similarly, the answers for marking painting and pothole repairs were demonstrated in Figure 5.5. A special variable was discussed for these two activities, namely “protection vehicle”. Currently there is a protection vehicle following the maintenance vehicle in these two activities. This variable was evaluated to discuss if the protection vehicle is still necessary when the maintenance vehicle becomes driverless.

![Figure 5.5 Results for Driverless Marking Painting and Pothole Repairs](image)

In driverless marking painting scenario, speed limit was assumed to remain the same and working speed was expected to increase. In addition, nighttime maintenance could be more frequent and protection vehicle is still necessary. In terms of impact on driver behaviors, it is possible road users will change lanes later. In driverless pothole repairs scenario, speed limit and working speed are both predicted to be the same. Protection vehicle is also still necessary to protect the maintenance vehicle. Furthermore, impact on driver behaviors would remain the same as well. As for working period, the frequency of the two answers are nearly the same. But even if half of the interviewees think nighttime maintenance would be easier, they also pointed out pothole repairs will be done as soon as possible usually, in order to avoid further deterioration and larger loss. For this reason, in spite of less traffic impact at night, maintenance would be finished immediately rather than be delayed to the night time. Consequently, driverless pothole repairs witnesses almost no difference compared to current situation. Therefore, it is not necessary to simulate this scenario.
Table 5.2 summarizes the characteristics of the three scenarios compared to the current situation and explains the reason why interviewees thought these changes will take place. Based on this information, traffic simulations in VISSIM were conducted in the following section.

<table>
<thead>
<tr>
<th>Maintenance Activity</th>
<th>Parameters</th>
<th>Current Situation</th>
<th>Driverless Maintenance</th>
<th>Reasons for Changes</th>
</tr>
</thead>
</table>
| **Mowing**           | Working period | Both daytime and nighttime | More often at night | (1) Nighttime maintenance has less traffic impact  
(2) No extra labor cost |
|                      | Working speed | 2-5 km/h          | Increase               | (1) Driverless maintenance could perform the task more accurately and faster  
(2) Humans could make mistakes sometimes |
|                      | Speed limit   | 70 km/h           | Increase               | (1) The consequence of crashing into driverless maintenance vehicles is reduced  
(2) The speed variance between road users and maintenance vehicles reduces |
|                      | Signs         | Work zone warning | No special signs       | Special signs will distract road users |
|                      | Impact on driver behaviors | Speed decrease, lane changing etc. | Remain the same | (1) Since there is no special signs, road users won’t realize the maintenance is driverless, then driver behaviors will remain the same  
(2) Even if they realize the maintenance is driverless, they will get used to it soon |
| **Lane Marking Painting** | Working period | Both daytime and nighttime | More often at night | (1) Nighttime maintenance has less traffic impact  
(2) No extra labor cost |
|                      | Working speed | 2-5 km/h          | Increase               | (1) Driverless maintenance could perform the task more accurately and faster  
(2) Humans could make mistakes sometimes |
|                      | Speed limit   | 70 km/h           | Remain the same        | The speed limit is not only designed for road workers but also for road users |
|                      | Signs         | Work zone warning and lane closure signs | No special signs | Special signs will make road users distracted |
|                      | Protection vehicle | Necessary | Still necessary | (1) The protection vehicle is used for warning  
(2) The maintenance vehicle is expensive, which still need protection |
|                      | Impact on driver behaviors | Speed decrease, lane changing etc. | Later lane changing | (1) Since there is no special signs, road users won’t realize the maintenance is driverless and remain the same behavior  
(2) Even if they realize the maintenance is driverless, they will get used to it soon |
As Table 5.2 shows, driverless mowing and marking painting would witness several changes in working condition parameters and impact on driver behaviors while driverless pothole repairs would basically remain the same situation. Hence, in the following section, simulations were only conducted for driverless mowing and marking painting scenarios.

5.3. Traffic Simulation of Driverless Maintenance Activities

This section described the settings and results of simulation in VISSIM. As explained above, only mowing and marking painting were selected as simulation scenarios. First of all, a 4000 m segment of a three-lane highway (including one shoulder) was selected as the test network. In the next place, the field traffic data collected from Dutch highway A59 Klaverpolder-south (51.695868,4.645407) was taken as the traffic flow input. The F/C (Flow/Capacity) rate of the traffic flow is 0.74, which means the traffic flow used is at non-peak hours without traffic jams. The speed limit of this road section is 130 km/h and the composition of vehicles is 70% of cars, 15% of small heavy goods vehicles and 15% of large heavy goods vehicles. Parameters of driving behaviors were set based on the study of Aries van Beinum (Aries, 2015), as it is demonstrated in Appendix E, in which the number of simulation runs and the confident interval of the results were explained as well. Additionally, based on the different characteristics of mowing and marking painting, dedicated traffic control was arranged, which were explained in next section. The moving work zones last 30 minutes and all the simulations last 40 minutes.
5.3.1. Mowing

Basic Scenario
The mowing vehicle works on the shoulder at the speed of 5 km/h and starts at the position of 1000m of the segment. The speed limit in work zones is 70 km/h, based on the regulations CROW (2017). Furthermore, according to CROW (2017), in Dutch highways, gantries, which display the speed limit and red crosses, are distributed in approximately every 500 meters and in the upstream of the working vehicle, there should be minimal one and maximal two red crosses and speed limit signs demonstrated, as Figure 5.6 shows. In the simulation, the first gantry is located at the position of 500m. Hence, the mowing work zone can be simulated as a moving speed reduction area in VISSIM.

Figure 5.6 Variable Message Signs

For instance, as Figure 5.7 shows, at the period of 0 - 360s (500m/(5 km/h)), the mowing vehicle is moving between 1000 - 1500m. Even though there is no lane closed, the speed limit signs at 500m, 1000m and 1500m should be displayed. Similarly, between 360 - 720s, the mowing vehicle is moving between 1500 - 2000m and the speed limit signs at 1000m, 1500m and 2000m should be displayed. Hence, each speed reduction area between two adjacent gantries exists for 720s, except for the area between 500 - 1000m and that between 3000 - 3500m, which both exist for only 360s.
The results of the basic scenario were demonstrated as following table:

<table>
<thead>
<tr>
<th>Normal Mowing</th>
<th>Average Speed (km/h)</th>
<th>Average Travel Time (s)</th>
<th>Average Delay (s)</th>
<th>Emissions (gram)</th>
<th>Fuel Consumption (gallon)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>83.53</td>
<td>168.36</td>
<td>24.36</td>
<td>13059.76</td>
<td>130.99</td>
</tr>
</tbody>
</table>

As indicated in Table 5.3, two groups of evaluation indicators were collected. The first one was related to traffic efficiency, including the average speed, average travel time and average delay of vehicles passing the whole road section, including work zones. The definition of delay here is subtracting the theoretical travel time (without other vehicles and traffic controls) from the actual travel time. The second one reflected the impact on environment, including emissions and fuel consumption. In normal mowing situation, the average speed of vehicles was 83.53 km/h, the average travel time was 168.36s and the average delay was 24.36s. In addition, the emissions reached 13059.76 grams and the fuel consumption was 130.99 gallon.

**Driverless Scenario 1: Increasing Speed Limit**

**Traffic Efficiency and Environment Impact Analysis**

In this scenario, the speed limit in work zones increased. It was uncertain by what degree would the speed limit go up, therefore, a sensitivity analysis was necessary. In the simulation, four different speed limits were tested, namely 80 km/h, 90 km/h, 100 km/h and 110 km/h. The results of different speed limits were shown as follows:
Table 5.4 Simulation Results of Different Speed Limits (1)

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>Average Speed (km/h)</th>
<th>Increased Average Speed vs. Basic Scenario (%)</th>
<th>Average Travel Time (s)</th>
<th>Increased Average Travel Time vs. Basic Scenario (%)</th>
<th>Average Delay (s)</th>
<th>Increased Average Delay vs. Basic Scenario (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 km/h</td>
<td>85.66</td>
<td>2.55%</td>
<td>164.42</td>
<td>-2.34%</td>
<td>20.42</td>
<td>-16.17%</td>
</tr>
<tr>
<td>90 km/h</td>
<td>86.06</td>
<td>3.03%</td>
<td>163.65</td>
<td>-2.80%</td>
<td>19.65</td>
<td>-19.33%</td>
</tr>
<tr>
<td>100 km/h</td>
<td>86.16</td>
<td>3.15%</td>
<td>163.46</td>
<td>-2.91%</td>
<td>19.46</td>
<td>-20.11%</td>
</tr>
<tr>
<td>110 km/h</td>
<td>86.24</td>
<td>3.24%</td>
<td>163.26</td>
<td>-3.03%</td>
<td>19.26</td>
<td>-20.94%</td>
</tr>
</tbody>
</table>

Table 5.5 Simulation Results of Different Speed Limits (2)

<table>
<thead>
<tr>
<th>Speed Limit</th>
<th>Emissions (grams)</th>
<th>Fuel Consumption (gallon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 km/h</td>
<td>13075.27</td>
<td>131.15</td>
</tr>
<tr>
<td>90 km/h</td>
<td>13131.64</td>
<td>131.71</td>
</tr>
<tr>
<td>100 km/h</td>
<td>13179.82</td>
<td>132.20</td>
</tr>
<tr>
<td>110 km/h</td>
<td>13180.31</td>
<td>132.20</td>
</tr>
</tbody>
</table>

Compared to the basic scenario, the traffic efficiency indicators were improved with increasing speed limit. When the speed limit varied between 70km/h and 110km/h, the higher the speed limit in work zones, the higher the average speed and the lower the average travel time and the average delay, as Figure 5.8 shows. In addition, the sharpest changes of three measures all happened when the speed limit increased from 70 km/h to 80 km/h. However, as Table 5.4 demonstrates, even if driverless maintenance vehicles could raise the speed limit to 110km/h, compared to the basic scenario, the increase of average speed was only 3.24% and the decrease of average travel time was only 3.03%, which is relatively small. But the reduction of average delay was 20.94%. A possible reason was that the maximal speed limit for HGV is 80 km/h. Even though cars were allowed to drive at the
speed of 110 km/h to pass the work zones, HGVs should comply with 80 km/h as well, which could properly explain why the greatest change in traffic efficiency indicators took place in the speed limit range [70 km/h, 80 km/h] and the increasing trend became slower after the speed limit was higher than 80 km/h. When it comes to environmental impacts, the increasing speed limit caused by driverless maintenance led to higher emissions and fuel consumption. It is reasonable that when vehicles were allowed to drive and they did drive at a higher speed, the emissions and fuel consumption would be higher as well, in order to support the increase in speed.

Traffic Safety Analysis
Another two measures for traffic safety analysis were selected, namely headway and speed distribution. The definition of headway here is the distance to the preceding vehicle divided by the speed of the vehicle. The speed distribution reflects the speed difference between different vehicles. Therefore, a larger headway or a denser speed distribution both means a lower probability of crashes. Figure 5.9 presents the change of the probability density function (PDF) of headway when the speed limit in work zones was increased. Figure 5.10 zooms in the difference of the five curves. In general, the PDF of headway remained the same as speed limit increased. But there were some subtle changes. The two peaks in the PDF became higher, which means the distribution of headway became more concentrated. But the right tail became smaller. Hence, with the increase of speed limit, the headway of vehicles was reduced and concentrated, increasing the probability of crashes. But this negative effect was not significant under 95% confident degree based on the K-S test, which was explained in Appendix E.

Figure 5.9 PDF of Headway in Different Speed Limits (1)
The change of the PDF of speed revealed the positive effect of increasing speed limit on traffic safety. As Figure 5.11 and Figure 5.12 demonstrate, the peak grew higher with increasing speed limit. The change was relative obvious when the speed limit increased from 70 km/h to 80 km/h. The PDF of speed became denser, which means the speed difference of vehicles decreased, reducing the probability of crashes and improving traffic safety. But the reduction of speed difference was not obvious when the speed limit is higher than 90 km/h. In conclusion, driverless mowing could both affect traffic safety negatively and positively by raising the speed limit in work zones. Because the headway of vehicles would be smaller and the speed difference would be reduced. Therefore, it is uncertain whether driverless mowing could improve traffic safety or not by increasing speed limit in work zones, given both positive and negative impacts. But it should be noticed that these impacts are not significant under 95% confidence level.
Based on the impacts on traffic efficiency, environment and traffic safety of growing speed limit in driverless mowing scenario, it is recommended that the speed limit could be increased from 70 km/h to 90 km/h. Even though the speed limit of 80 km/h witnessed the largest increasing positive impact on traffic efficiency and the least increasing negative impact on environment, Rijkswaterstaat won’t probably apply it because the speed limit step of 20 km/h is more regular, such as the common used “70 km/h, 90 km/h” regulation or the “80 km/h, 100 km/h” regulation in some areas. The speed limit of 90 km/h is regarded as
more applicable and road users are more used to that. In addition, this adjustment could be beneficial to traffic efficiency and environment but a higher speed limit is not effective.

**Driverless Scenario 2: Increasing Working Speed**

**Traffic Efficiency and Environment Impact Analysis**

In this scenario, the working speed of the mowing vehicle increased. It is also uncertain about the change degree, therefore, a sensitivity analysis was also conducted. In the simulation, five different working speed were compared, namely 6 km/h, 7 km/h, 8 km/h and 9 km/h. When the working speed of the mowing vehicle increased, the duration of the existence of work zones would be reduced and the time interval when the working vehicle moved between two gantries would also decrease. For instance, in the basic scenario, the working speed of the maintenance vehicle was 5 km/h, therefore the time interval mentioned above was 360s. When the working speed increased to 6 km/h, the time interval was reduced to only 300s (500m/6 km/h). The results of different working speed were demonstrated as follows:

<table>
<thead>
<tr>
<th>Working Speed (km/h)</th>
<th>Average Speed (km/h)</th>
<th>Increased Average Speed vs. Basic Scenario (%)</th>
<th>Average Travel Time (s)</th>
<th>Increased Average Travel Time vs. Basic Scenario (%)</th>
<th>Average Delay (s)</th>
<th>Increased Average Delay vs. Basic Scenario (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 km/h</td>
<td>83.88</td>
<td>0.42%</td>
<td>167.80</td>
<td>-0.33%</td>
<td>23.80</td>
<td>-2.30%</td>
</tr>
<tr>
<td>7 km/h</td>
<td>84.14</td>
<td>0.73%</td>
<td>167.25</td>
<td>-0.66%</td>
<td>23.25</td>
<td>-4.56%</td>
</tr>
<tr>
<td>8 km/h</td>
<td>84.33</td>
<td>0.96%</td>
<td>166.89</td>
<td>-0.87%</td>
<td>22.89</td>
<td>-6.03%</td>
</tr>
<tr>
<td>9 km/h</td>
<td>84.51</td>
<td>1.17%</td>
<td>166.56</td>
<td>-1.07%</td>
<td>22.56</td>
<td>-7.39%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Working Speed</th>
<th>Emissions (grams)</th>
<th>Fuel Consumption (gallon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 km/h</td>
<td>13086.16</td>
<td>131.26</td>
</tr>
<tr>
<td>7 km/h</td>
<td>13104.30</td>
<td>131.44</td>
</tr>
<tr>
<td>8 km/h</td>
<td>13117.95</td>
<td>131.57</td>
</tr>
<tr>
<td>9 km/h</td>
<td>13128.72</td>
<td>131.68</td>
</tr>
</tbody>
</table>
As the working speed of driverless maintenance vehicle increased, the traffic efficiency indicators also witnessed positive changes. When the working speed varied from 5 km/h to 9 km/h, the average speed of vehicles can increase by maximal 1.17% and the average travel time can decrease by maximal 1.07%, in spite of the exiguity. However, the average delay could be reduced by 7.39%, as Table 5.6 demonstrates. When the driverless maintenance vehicle speeded up from 6 km/h to 7 km/h, the greatest positive change in traffic efficiency would be realized with the most significant decrease in average travel time and average delay, as demonstrated in Figure 5.13. In the perspective of environmental impacts, the increasing working speed also resulted in higher emissions and fuel consumption. The reason was that the duration of speed limit was reduced, therefore vehicles could recover to normal higher speed sooner, which needed more energy and causes more pollution.

Traffic Safety Analysis
The PDF of headway and speed distribution of vehicles were also compared in this scenario. As Figure 5.14 and Figure 5.15 show, the PDF of headway has hardly no change with increasing working speed of the mowing vehicle, in spite of the trivial growth of the peak and small decrease in average. Another measure, the distribution of speed displayed a more complicated change. As demonstrated in Figure 5.16 and Figure 5.17, the lower peak decreased with higher working speed while the higher peak increased. Hence, the PDF of speed became denser and the speed difference between vehicles was reduced. It is concluded that by improving the working speed, driverless mowing could reduce headway and speed difference between vehicles at the same time. Whether traffic safety could be improved or not cannot be decided either. Also, the impact on traffic safety in this scenario is not significant under 95% confidence level.
Figure 5.14 PDF of Headway in Different Working Speeds (1)

Figure 5.15 PDF of Headway in Different Working Speeds (2)
Based on the impacts on traffic efficiency, environment and traffic safety of growing working speed in driverless mowing scenario, it is recommended that the working speed could be increased from 5 km/h to 7 km/h so that the greatest improved traffic efficiency and the least negative changed environment could be generated. In addition, the traffic safety would nearly remain the same. Similarly, a higher working speed would not be effective due to increasing pollution and energy consumption.
Combined Driverless Scenario 1 & 2
Traffic Efficiency and Environment Impact Analysis

In the previous sections, the impact of increasing speed limit and that of increasing working speed were investigated separately. Driverless maintenance vehicles could realize these two impacts in the meantime. Hence, combined scenarios simulations were conducted to investigate the integrated influence.

In general, the average speed of vehicles increased with higher speed limit in work zones and higher working speed of driverless maintenance vehicles. However, the increase was not unlimited. As Table 5.8 shows, when the speed limit in work zones reached 90 km/h, there was almost no change in average speed no matter how working speed changed. In addition, when the speed limit varied from 70 km/h to 80 km/h, which was 14.3% higher than before, the average speed change (2.55%) was higher than that (1.17%) when the working speed of driverless maintenance vehicles increased to 9 km/h. It is reasonable to conclude that the average speed is more sensitive to the change of speed limit. This could be reflected in Figure 5.18 in a more visualized way, in which the distribution of average speed was flat along the axis of working speed while it took on a ramp along the axis of speed limit. In practice, it is also much easier to make adjustments to the speed limit while it requires technical development to double the working speed of maintenance vehicles. Hence, changing speed limit in driverless maintenance situations is expected to more effective and doable. However, even if the speed limit was altered to 110 km/h, the average speed would merely increase by 3.16%.

<table>
<thead>
<tr>
<th>Working Speed (km/h)</th>
<th>Average Speed Change</th>
<th>Speed Limit (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>5</td>
<td>0.00%</td>
<td>2.55%</td>
</tr>
<tr>
<td>6</td>
<td>0.42%</td>
<td>2.66%</td>
</tr>
<tr>
<td>7</td>
<td>0.73%</td>
<td>2.68%</td>
</tr>
<tr>
<td>8</td>
<td>0.96%</td>
<td>2.74%</td>
</tr>
<tr>
<td>9</td>
<td>1.17%</td>
<td>2.79%</td>
</tr>
</tbody>
</table>
The average travel time change witnessed the opposite trend to that of the average speed. Even though both speed limit increase and working speed increase would both reduce average travel time of vehicles through work zones, the decrease was also restricted. As Table 5.9 shows, with 90 km/h or higher speed limit, there was hardly no difference between the average travel time change when the working speed changed. Additionally, the degree of reduction in average travel time when speed limit increased from 70 km/h to 80 km/h was larger than that when working speed was improved from 5 km/h to 9 km/h. It is convinced that average travel time is also more sensitive to the change of speed limit. Figure 5.19 reflects the uneven distribution of average travel time as well. However, even the highest speed limit in the simulations, namely 110 km/h could only reduce the average travel time by 3.04%.

<table>
<thead>
<tr>
<th>Working Speed (km/h)</th>
<th>Average Travel Time Change</th>
<th>Speed Limit (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>5</td>
<td>0.00%</td>
<td>-2.34%</td>
</tr>
<tr>
<td>6</td>
<td>-0.33%</td>
<td>-2.51%</td>
</tr>
<tr>
<td>7</td>
<td>-0.66%</td>
<td>-2.56%</td>
</tr>
<tr>
<td>8</td>
<td>-0.87%</td>
<td>-2.61%</td>
</tr>
<tr>
<td>9</td>
<td>-1.07%</td>
<td>-2.73%</td>
</tr>
</tbody>
</table>
The average delay change demonstrated a similar trend as the average travel time change. Overall speaking, it became smaller with increasing speed limit and working speed, as Figure 5.20 shows. Similarly, the average delay change is also more sensitive to the change of speed limit. As Table 5.10 demonstrates, when the speed limit increased to 110 km/h, the average delay could decrease by more than 20%. In addition, when speed limit was 70 km/h, working speed could affect the average delay change more significantly. When the working speed increased from 5 km/h to 9 km/h, the average delay was reduced by 7.39%. However, this positive effect was much smaller when the speed limit was higher.

Table 5.10 Average Delay Change in Combined Scenarios

<table>
<thead>
<tr>
<th>Average Delay Change</th>
<th>Speed Limit (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70</td>
</tr>
<tr>
<td>5</td>
<td>0.00%</td>
</tr>
<tr>
<td>6</td>
<td>-2.30%</td>
</tr>
<tr>
<td>Working Speed (km/h)</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>
By raising speed limit in work zones and speeding up, driverless maintenance vehicles produced more emissions, as Table 5.11 indicates. Figure 5.21 reveals that the change of speed limit from 80 km/h to 100 km/h would induce the sharpest emissions growth. Hence, it is concluded that even if higher speed limit and working speed can improve traffic efficiency, it can do harm to environment as well. Fortunately, the negative effect was small. In the simulations, the largest emissions growth was only 1.02%.

Table 5.11 Emissions Change in Combined Scenarios

<table>
<thead>
<tr>
<th>Working Speed (km/h)</th>
<th>Speed Limit (km/h)</th>
<th>Emissions (gram)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>0.00%</td>
<td>0.12%</td>
</tr>
<tr>
<td>6</td>
<td>0.20%</td>
<td>0.26%</td>
</tr>
<tr>
<td>7</td>
<td>0.34%</td>
<td>0.39%</td>
</tr>
<tr>
<td>8</td>
<td>0.45%</td>
<td>0.47%</td>
</tr>
<tr>
<td>9</td>
<td>0.53%</td>
<td>0.55%</td>
</tr>
</tbody>
</table>
Fuel consumption change was faced with the same situation as emissions change. Improvements in speed limit and working speed would induce growth of fuel consumption as well. The sharpest change also took place between speed limit of 80 km/h and 100 km/h, as Figure 5.22 shows. Furthermore, as Table 5.12 demonstrates, it was also fortunate the increase of fuel consumption remained as a small extent, which in the simulations was maximal 1.02% as well.

Table 5.12 Fuel Consumption Change in Combined Scenarios

<table>
<thead>
<tr>
<th>Working Speed (km/h)</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.00%</td>
<td>0.12%</td>
<td>0.55%</td>
<td>0.92%</td>
<td>0.92%</td>
</tr>
<tr>
<td>6</td>
<td>0.21%</td>
<td>0.27%</td>
<td>0.64%</td>
<td>0.96%</td>
<td>0.97%</td>
</tr>
<tr>
<td>7</td>
<td>0.34%</td>
<td>0.39%</td>
<td>0.71%</td>
<td>0.98%</td>
<td>0.99%</td>
</tr>
<tr>
<td>8</td>
<td>0.44%</td>
<td>0.47%</td>
<td>0.76%</td>
<td>1.00%</td>
<td>1.01%</td>
</tr>
<tr>
<td>9</td>
<td>0.53%</td>
<td>0.55%</td>
<td>0.80%</td>
<td>1.02%</td>
<td>1.02%</td>
</tr>
</tbody>
</table>
5.3.2. Marking Painting

Basic Scenario

The marking painting vehicle works on one of the lane at the speed of 5 km/h, followed by a protection vehicle with 100 meters’ distance behind. The speed limit is also 70 km/h. As Figure 5.23 shows, compared to mowing activity, not only the speed limit signs should be displayed on the gantries, but also red crosses are necessary to warn road users of the closure of the lane.
When the marking painting vehicle works on the right lane, then only the left lane is accessible and it could be simulated as a moving speed reduction area as well. Similarly, on the right lane, a moving closed zone could be simulated. For instance, as it is shown in Figure 5.23, at the period of 0 - 360s (500m/(5km/h)), both the marking painting vehicle and the protection vehicle are moving between 1000 - 1500m. Then the area between 500m and 1500m is closed. Similarly, between 360 - 720s, the two vehicles are moving between 1500 - 2000m and the closed zone expands from 1000m to 2000m. When the two vehicles working on the left lane, then the closed zone is simulated on the left lane and the speed reduction area is simulated on the right lane.

**Driverless Scenarios**

Based on the interviews, there were also two possible driverless marking painting scenarios. In the first one, the working speed of the marking painting vehicle would increase so that the moving speed of speed reduction zones and closed zones would also increase. In the second scenario, the lane changing mode of users would change. According to the interviewees, road users tend to change their lane later because they would be more willing to take risks since there is no road worker in the work zones. These two scenarios could be simulated to compare with the basic scenario, observing the differences in traffic safety and efficiency and environment measures, as Section 5.3.1 demonstrated. However, it was found that the simulation of the dynamic lane closure in VISSIM was quite difficult and not realized in the period of this study. It is recommended that future research could investigate this scenario with VISSIM or other microscopic traffic simulation software.

**5.4. Summary**

Based on literature review, this chapter explained the design of the interview protocol, including the selected scenarios and chosen parameters for discussion. Interviewees were asked to answer the change of speed limit, working period, working speed, driver behaviors etc. in three different scenarios, including driverless mowing, driverless marking painting and driverless pothole repairs.

The results of interviews showed that mowing and marking painting could witness more evident change in the chosen parameters when driverless maintenance is implemented. For instance, driverless mowing was believed to increase working speed and speed limit of work zones and make nighttime maintenance more frequent. Driverless marking painting was believed to increase working speed and the frequency of nighttime maintenance as well. However, driverless pothole repairs were not expected to make any changes. Hence, only mowing and marking painting were selected to conduct simulations, in order to further investigate the traffic impacts of driverless maintenance.

In the simulations of mowing activity, a moving speed reduction area was simulated and driverless mowing was thought to increase the value of speed limit and the moving speed of the speed reduction area. Compared to the traditional mowing, when the speed limit was raised (changing from 70 km/h to 110 km/h), driverless mowing could increase the average speed by maximal 3.24% and reduce the average travel time and average delay by maximal 3.03% and 20.94% respectively. However, the emissions and fuel consumption were
increased. In particular, when the speed limit increased from 70 km/h to 80 km/h, the positive impact on traffic efficiency was the most effective and the negative impact on environment was the least significant. As for the traffic safety, increasing speed limit in driverless mowing scenario could reduce the headway and the speed difference of road users. But the impact is not significant under 95% confidence level.

When the working speed of driverless mowing vehicle increased (changing from 5 km/h to 9 km/h), the average speed could be increased by maximal 1.17% and the average travel time and the average delay could be reduced by maximal 1.07% and 7.39%. Again, emissions and fuel consumption were increased as well. In particular, when the working speed increased from 6 km/h to 7 km/h, the positive impact on traffic efficiency was the greatest and the negative impact on environment was the least. In terms of traffic safety, the increasing working speed of driverless mowing vehicle could reduce the headway and the speed difference of road users as well. Again, this impact is not significant under 95% confidence level.

When the speed limit and working speed increased at the same time, it is concluded that most parameters, including average speed, average travel time, emissions and fuel consumption, were more sensitive to speed limit change than working speed change. When the speed limit reached 90km/h or even higher, working speed had almost no influence on the parameters at all. Hence, considering the regulation of 20 km/h speed limit step, when driverless mowing is implemented, it is recommended to raise the speed limit to 90km/h and increase the working speed to 7 km/h.
6. Cost-Benefit Analysis
Since the implementation of driverless maintenance would influence the highway system and change the social welfare such as traffic safety and efficiency, Cost-Benefit Analysis (CBA) was applied in this research to make an assessment from an economical perspective.

**Definition**
CBA is a tool for assessing policy options from the perspective of social welfare change (European Commission, 2014). This tool provides a quantitative weighing of the resulting costs and benefits of a policy measure to the whole society, by assigning values to the social welfare effects (Romijn & Renes, 2013). The balance of benefits and costs reflects not only the social welfare changes with market price but also those without market price and related to the willingness to pay, such as pollution, safety etc. (Romijn & Renes, 2013).

**Purpose**
The main goal of CBA is to support decision-making process by providing monetary expressions of social welfare changes of a certain policy option. An explicit and easily understandable comparison of pros and cons reveals the results of a measure and provides the answer of the question whether the plan could be economically justified (Romijn & Renes, 2013). The outcome of CBA is also expected to facilitate an efficient resources distribution, demonstrating the interest of society as a whole and optimizing the selection of interventions (European Commission, 2014; Romijn & Renes, 2013). In addition, the results of CBA could strengthen the confidence of stakeholders, obtaining more supports from different parties. In return, the involvement of stakeholders in CBA is also crucial and even a key factor in decision-making (Bertolini, 2013). Hence, in this research, interviews and questionnaires are also designed to collect information from stakeholders in order to conduct CBA.

**Procedures**
In this research, the process of CBA would be based on the steps listed in General Guidance for Cost-Benefit Analysis from CPB Netherlands Bureau for Economic Policy Analysis and PBL Netherlands Environmental Assessment Agency. Eight steps could be found in the Figure 6.1, in which the first three steps form the preparation stage, Steps 4&5, as the focus of CBA, identify and quantify the costs and benefits, Step 6 analyzes the factors possibly influencing the outcome of CBA and Steps 7&8 summarize and present the results of CBA.
In this study, the cost benefit analysis was conducted from the perspective of the whole society. Driverless maintenance serves as the policy alternative in Step 3 and normal highway maintenance is regarded as the baseline alternative in Step 2. In this chapter, normal mowing and driverless mowing were compared. Based on the results from interviews and traffic simulation in previous chapters, the benefits and costs of driverless maintenance were identified as follows:
6.1. Determine Benefits

The extra benefits of driverless mowing compared to traditional mowing include:

(1) **Reduction of Injuries and Death**: driverless mowing prevents possible injuries and death of road workers. It lacks statistical results of the injuries and death involving mowing but based on interview C6, mowing is relative safe and seldom witnesses accidents. Hence, this benefit was regarded as a variable for sensitivity analysis.

(2) **Reduction of Labor Costs**: driverless mowing requires no worker sitting in the vehicle. Based on the expectation of interviewee C6, driverless mowing can save 30 euro per hour compared to traditional mowing due to the reduction of labor costs.

(3) **Reduction of Travel Time**: the simulation in Section 5.3 revealed that driverless mowing is able to reduce the average travel time of vehicles passing road work zones. In this case, the driverless mowing vehicle works at the speed of 7 km/h and raises the speed limit to 90 km/h. According to Table 5.9, the average travel time was reduced by 5s in 30 minutes’ duration of road work.

There are another two benefits, which are hard to estimate or less related to mowing but applicable in other driverless maintenance cases.

(1) **Reduction of Safety Measures**: according to interviewee C5, driverless maintenance is able to reduce expensive safety measures because there is no road worker requiring protection. But in mowing case, the safety measures are already very simple. In addition, interviewee C5 also stated that it is uncertain that which safety measures should be moved first. This benefit should be further investigated after pilot tests.

(2) **Creating New Database**: as described in Section 4.3.3, driverless maintenance could generate lots of data, which is helpful to develop preventive maintenance and make contributions to general automated driving technology development. This benefit is a long-term effect and hard to transfer to monetary value.

In the cost benefit analysis, only the first three benefits were taken into consideration. The latter two were thought to be variants and risks and were not included in this rough cost benefit analysis.

6.2. Determine Costs

The additional costs of driverless mowing compared to traditional mowing include:

(1) **Technical Investment**: the technical investment for driverless mowing vehicle depends on the technical route map. Interviewee E1 stated that there were major two ways of development, including equipping the normal vehicle with automated driving technology and inventing a new type of vehicle. Interviewee C1, C2 and E1 agreed that by choosing the latter solution, the vehicle size can be reduced and even
the cabin can be removed. But interviewee D1 regarded the former alternative as the most potential solution. From the perspective of manufacturers, inventing a new type of vehicle requires the change of production line, which will lead to much more costs compared to the savings in reducing the size and parts of vehicles. Interviewee C3-C7 also added that the great change of the appearance of maintenance vehicles can cause a large distraction to road users. Hence, in this case, the technical investment is based on transferring the current vehicle into a driverless one. According to interviewee E1, the investment could be 50000-100000 euro or even more. Interview A6 thought the cost could reach 200000 euro per vehicle. As a reference, the driverless protection vehicle costs Colorado Department of Transportation 300000 dollars (Lounsberry, 2017). In this case, an average amount of 200000 euro and 300000 dollars, namely 225000 euro per vehicle was selected.

(2) Increased Emissions: the results of simulation in Section 5.3 showed that the implementation of driverless mowing vehicle would increase emissions. As indicated in Table 5.11, when driverless mowing vehicle speeds up to 7 km/h and the speed limit is increased to 90 km/h, emissions increased by approximately 92.5 grams when the duration of work zones is 30 minutes.

(3) Increased Fuel Consumption: Similarly, fuel consumption was raised due to driverless mowing as well. As demonstrated in Table 5.12, in the combined scenario with working speed of 7 km/h and speed limit of 90 km/h, fuel consumption increased by around 1 gallon when work zones exist for 30 minutes.

Same as benefits, there are also some costs, which are hard to evaluate or transfer into money.

(1) Maintenance Cost of Vehicle & Systems: the technical investment only includes the production cost of vehicles. The maintenance cost of the vehicles and the whole self-driving system is not predictable at the present. A major reason is that the reliability and functionality of the system are still uncertain and the maintenance cost is largely sensitive to the technical failures.

(2) Short-term Job Loss: the implementation of driverless mowing vehicle protects road workers from potential accidents. At the meantime, it makes those people unemployed. The job loss is thought to be a cost of driverless mowing, according to interviewee from different parties such as A4, B2, C4, D1. But they also believed this cost is temporary.

(3) Pilot Test Costs: the implementation of driverless mowing vehicle should go through the pilot test first. Interviewee E1 provided an estimation of 50000-70000 euro per test. However, this cost was not taken into account due to its high uncertainty as well. As mentioned in Section 4.3.2, in the Netherlands, driverless vehicles are allowed to be tested after exemption. But every time the driverless maintenance vehicle need work on the road, it has to go through the whole exemption process all over again, based on the current law and regulations. It is uncertain that whether driverless
maintenance vehicles could go through the exemption only once and receive legalization in the future. This cost is affected by large political uncertainties and therefore it was excluded from this rough cost benefit analysis. But it should be taken into account in the future.

(4) **Extra Job Opportunities**: even though driverless mowing vehicle doesn’t require a driver, it still needs a remote supervisor and staff for the maintenance of the information system, which will generate extra job opportunities. This is an extra cost for the whole society to support the implementation of driverless maintenance. However, it is hard to estimate the added cost due to the uncertain number of job positions.

In the cost benefit analysis, only the first three costs were taken into consideration. The latter four were thought to be variants and risks and were not included in this rough cost benefit analysis.

### 6.3. Overview of Costs and Benefits

The cost benefit analysis was conducted in a time span of 20 years from 2020 to 2040. *Table 6.1* presents an overview of the costs and benefits of driverless mowing. *Appendix F* explained the assumptions and the calculations of costs and benefits of driverless mowing in more details.

<table>
<thead>
<tr>
<th>Driverless Mowing</th>
<th>Total Value</th>
<th>Total Net Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits (euro)</td>
<td>460,000 (1 light injury)</td>
<td>350,000 (1 light injury)</td>
</tr>
<tr>
<td></td>
<td>6,200,000 (1 severe injury)</td>
<td>4,700,000 (1 severe injury)</td>
</tr>
<tr>
<td></td>
<td>55,200,000 (1 death)</td>
<td>41,700,000 (1 death)</td>
</tr>
<tr>
<td>(1) Reduction of Death and Injuries</td>
<td>180,000 (1 light injury)</td>
<td>140,000 (1 light injury)</td>
</tr>
<tr>
<td></td>
<td>5,900,000 (1 severe injury)</td>
<td>4,400,000 (1 severe injury)</td>
</tr>
<tr>
<td></td>
<td>54,900,000 (1 death)</td>
<td>41,500,000 (1 death)</td>
</tr>
<tr>
<td>(2) Reduction of Labor Costs</td>
<td>200,000</td>
<td>150,000</td>
</tr>
<tr>
<td>(3) Reduction of Travel Time</td>
<td>76,000</td>
<td>76,000</td>
</tr>
<tr>
<td>Costs (euro)</td>
<td>540,000</td>
<td>460,000</td>
</tr>
<tr>
<td>(1) Technical Investment</td>
<td>450,000</td>
<td>400,000</td>
</tr>
<tr>
<td>(2) Increased Emissions</td>
<td>7,000</td>
<td>5,000</td>
</tr>
<tr>
<td>(3) Increased Fuel Consumption</td>
<td>74,000</td>
<td>56,000</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td>-120,000 (1 light injury)</td>
<td>41,000,000 (1 death)</td>
</tr>
<tr>
<td></td>
<td>5,700,000 (1 severe injury)</td>
<td>4,200,000 (1 severe injury)</td>
</tr>
<tr>
<td></td>
<td>54,700,000 (1 death)</td>
<td>41,000,000 (1 death)</td>
</tr>
</tbody>
</table>

Rijkswaterstaat provides a standard discount rate of 3% for societal cost benefit analysis. All benefits and costs were discounted to the year 2020 to calculate the net present value of
implementing driverless mowing. As indicated in Table 6.1, when there is 1 light injury saved, the net present value is -1200000 euro, which means in a time span of 20 years, if driverless mowing vehicle is put into use in 2020 and can only avoid 1 light injury every year, it is not worth making the investment. When there is 1 severe injury or 1 death saved, the net present value is 42000000 euro and 41000000 euro respectively. It is noticed that even if only 1 severe injury or 1 death is saved during the whole 20 years, the net present value is still positive. It is concluded that the net present value of implementing driverless mowing is very sensitive to the safety improvements. As long as 1 severe injury could be avoided during the life cycle of the driverless mowing vehicle, it is cost benefit effective to apply driverless mowing vehicle.

It should be noticed that the cost benefit analysis conducted in this chapter was only based on driverless mowing scenario and a societal perspective. The results would vary when different driverless scenarios are considered, such as marking painting, or when different perspectives are selected, such as from the standing of market parties, namely manufacturers and contractors.

Take driverless marking painting scenario as an example, not only the painting vehicle but also the protection vehicle should be replaced with a driverless one, which at least doubles the technical investments compared to driverless mowing scenario. On the other hand, since the marking painting vehicle works on one of the lane rather than on the shoulder and requires temporary lane closure, it affects larger impact on traffic safety and efficiency. When driverless marking painting is implemented, it is possible to reduce more injuries or death, therefore, to bring more benefits.

As for different perspectives, based on interviewee C1 and C2, the expected return period of investments for contractors is around 5 years. Based on interviewee D1, the expected return period for manufacturers is only 2-3 years when there is no investor. With investors, the expected return period could be extended to 4-5 years or even longer, which means market parties will allow a shorter period to achieve a positive net present value. In addition, both contractors and manufacturers will choose their own discount rate, which will be higher than the societal discount rate, to calculate net present value of making an investment. The composition of costs and benefits also differs for different stakeholders. For instance, the increased emission was regards as a cost for the whole society, while it will not be taken into account in the cost benefit analysis of market parties. In this chapter, a time span of 20 years and a societal discount rate of 3% were selected. In the business case of market parties, the time span would be reduced to 5 years and a much higher commercial discount rate would be determined to conduct the cost benefit analysis.

6.4. Summary

This chapter selected driverless mowing as the policy alternative and regarded traditional mowing as the baseline alternative. Compared to traditional mowing, the extra benefits and costs of driverless mowing were identified and calculated. In addition, variables and risks of costs and benefits were also discussed.
Table 6.2 Cost Benefit Analysis of Driverless Mowing (2)

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculable Parameters</td>
<td></td>
</tr>
<tr>
<td>Reduction of death and injuries</td>
<td>Reduction of labor costs</td>
</tr>
<tr>
<td>Reduction of travel time</td>
<td>Technical investment</td>
</tr>
<tr>
<td>Reduction of emissions</td>
<td>Increased fuel consumption</td>
</tr>
<tr>
<td>Variables &amp; Risks</td>
<td></td>
</tr>
<tr>
<td>Reduction of safety measures</td>
<td>Creating new database</td>
</tr>
<tr>
<td>Maintenance costs of vehicle &amp; systems</td>
<td>Short-term job loss</td>
</tr>
<tr>
<td>Maintenance costs of vehicle &amp; systems</td>
<td>Pilot test costs</td>
</tr>
<tr>
<td></td>
<td>Extra job opportunity</td>
</tr>
</tbody>
</table>

In order to quantify the benefits and costs, driverless mowing scenario was further specified, in which the mowing vehicle works at the speed of 7 km/h and the speed limit in work zones is 90 km/h. The maintenance task lasts 8 hours per day and 20 days per month and 2 months per year. And the life cycle of the mowing vehicle is 10 years. Based on these assumptions, the net present value of implementing driverless mowing was calculated in a time span of 20 years, with a sensitivity analysis by changing the reduction of death and injuries.

Table 6.3 Results of Cost Benefit Analysis

<table>
<thead>
<tr>
<th>NPV (euro)</th>
<th>Reducing 1 light injury per year</th>
<th>Reducing 1 severe injury per year</th>
<th>Reducing 1 death per year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-120000</td>
<td>4200000</td>
<td>4100000</td>
</tr>
</tbody>
</table>

As Table 6.3 shows, the net present value is very sensitive to the safety improvements of implementing driverless mowing. Besides, there are other factors influencing the results of cost-benefit analysis, such as different maintenance scenarios and perspectives of analysis. Both factors could change the composition of costs and benefits and the latter could even change the discount rate and time span of analysis. But to crown the whole, from the societal perspective, as long as 1 severe injury or 1 death per year could be avoided, it is worthwhile to invest on driverless mowing.
7. Conclusion and Recommendations
This chapter summarized the main findings and provided conclusions of this study. First of all, the main research question and five sub-questions raised in Section 1.2 were answered. In the next place, the scientific contributions of this study were discussed. Additionally, the practical applications obtained from this study were demonstrated. Last but not least, the recommendations for future research were presented.

### 7.1. Answers to Research Questions

One of the research objectives of this study is to investigate the feasibility of implementing driverless maintenance in dynamic highway construction zones. Five sub-questions were organized to realize the objective. The first question was interpreted as:

**How do highway construction zones affect the traffic safety and efficiency currently?**

By comparing the regulations of the layout of highway construction zones in the Netherlands (CROW) and America (MUTCD), it was found that highway construction zones change the traffic conditions by closing part of the roads with cones or barriers and implementing traffic controls, such as speed limits. When it comes to dynamic work zones, variable message signs and rear-end protection vehicles are two major measures to warn road users of the existence of work zones. Due to the significant changes of traffic conditions, traffic safety and efficiency of the road section are affected. By conducting literature review, the influence from highway construction zones could be summarized in the following table:

<table>
<thead>
<tr>
<th>Traffic Safety</th>
<th>Traffic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash rate</td>
<td>Increase by around 20%</td>
</tr>
<tr>
<td>Crash severity</td>
<td>2% fatal accidents of all 23 victims in 22 collisions and 5 of them died</td>
</tr>
<tr>
<td>Crash locations</td>
<td>Activity area and buffer area</td>
</tr>
<tr>
<td>Crash time</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Crash types</td>
<td>Rear-end crashes</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In terms of the impact on traffic safety, highway construction zones raise the crash rate by around 20% and witness rear-end crashes most frequently, in particular in the activity area and buffer area. Among all fatal accidents on roads, construction zones witnessed 2% of them. In terms of the impact on traffic efficiency, highway construction zones reduce the speed of road users by around 30 km/h in average and reduce the road capacity by around 8%-17%, therefore, increasing congestions and delay. However, unreasonable settings of speed limits, such as during the period when the construction work is not visible or when the construction work is finished, lead to poor compliance of road users, which cast threats to
the traffic safety in turn. In conclusion, highway construction zones affect the traffic safety and efficiency negatively by increasing crash rate, congestions and delay and reducing road capacity and speed limits.

The negative effects of highway construction zones on traffic safety and efficiency explain why it is potential to implement driverless maintenance, which is expected to set free road workers out of construction zones and reduce traffic protection measures, leading to improvements in traffic safety and efficiency. Hence, it is reasonable to ask the second question:

*What are the current and future potential applications of driverless maintenance in dynamic highway construction zones?*

This study provided an overview of the development of driverless maintenance all over the world. First of all, two levels of automation in maintenance were identified, namely Level 1: the automation of operating maintenance tasks and Level 2: the automation of both operating tasks and moving to next maintenance area. Driverless maintenance refers to the latter, which removes both operators and drivers from the maintenance vehicle. *Table 3.1* presented a list of products from these two different levels, in which seven driverless maintenance practices were stressed, including:

<table>
<thead>
<tr>
<th>Driverless Maintenance Practices</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>The autonomous weeder platform</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>The automated tunnel lighting fixture cleaning vehicle</td>
<td>Japan</td>
</tr>
<tr>
<td>The driverless protection vehicle</td>
<td>Germany, America, 3 examples in total</td>
</tr>
<tr>
<td>The self-driving marking painting vehicle</td>
<td>Russia</td>
</tr>
<tr>
<td>The automated snow plow vehicle</td>
<td>Japan</td>
</tr>
</tbody>
</table>

However, all these driverless maintenance vehicles are still at the stage of pilot tests and not widely applied yet. In the next place, a series of common highway maintenance activity was identified. The activities, which have realized or are experiencing the two levels of automation, were regarded to be the first group of potential driverless maintenance applications. The reason is that based on the automation, in spite of the level, it is easier to develop into full driverless maintenance implications. Hence, totally seven maintenance activities were expected to achieve driverless maintenance first, including:
<table>
<thead>
<tr>
<th>Activity</th>
<th>Level of Automation Now</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mowing</td>
<td>Level 1</td>
</tr>
<tr>
<td>Paint and bead striping</td>
<td>Level 2 (pilot test)</td>
</tr>
<tr>
<td>Litter removal (asphalt cleaning)</td>
<td>Level 2 (pilot test)</td>
</tr>
<tr>
<td>Pothole repairs</td>
<td>Level 1</td>
</tr>
<tr>
<td>Illumination cleaning</td>
<td>Level 2 (pilot test)</td>
</tr>
<tr>
<td>Assistance to traffic (protection vehicle)</td>
<td>Level 2 (pilot test)</td>
</tr>
<tr>
<td>Sealing cracks &amp; joints</td>
<td>Level 1</td>
</tr>
</tbody>
</table>

By answering the second question, an international perspective of the development of driverless maintenance and a reference list for future development was provided. In order to develop driverless maintenance, it is inevitable to ask the third question:

*How are related stakeholders involved in the driverless maintenance?*

This study provided a list of major stakeholders for driverless maintenance development, including The Ministry of Infrastructure and Water Management, road authority, vehicle authority, contractors, manufacturers, research institutions, road users, road workers and insurance companies. Based on 20 interviews with these stakeholders, a stakeholder matrix (*Table 4.2*) and a power-interest grid (*Figure 4.4*) were constructed to compare the interest, alliances, resources and power of different stakeholders. Based on the stakeholder matrix, it is concluded that The Ministry, road authority and contractors have the most diverse interest. Both road authority and vehicle authority participate in the alliances with government institutions and that with market organizations, therefore serving as the bridge between policy making parties and market parties. Among the stakeholders, The Ministry, road authority, contractors, manufacturers and research institutions own the most and also the most diverse resources for the development of driverless maintenance. In particular, the technical resources accumulate in market parties while the political resources are owned by government institutions, which also hold high authority in the implementation of driverless maintenance. In the power-interest grid, The Ministry, road authorities are located in “high power & high interest” region. Vehicle authority is located in “high power & low interest” region. Contractors and manufacturers are located in “low power & high interest” region but they do have medium power in some technical and commercial issues. Research institutions, road workers, road users and insurance companies are located in “low power & low interest” region but research institutions and unions of road users or road workers do have medium power based on their technical resources (research institutions) and political resources
(unions of road users or road workers). The involvement strategy towards different stakeholders is summarized below based on Byson (2004).

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Involvement Strategy</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Ministry</td>
<td>Empower</td>
<td>Implement the decision</td>
</tr>
<tr>
<td>Road authority</td>
<td>Collaborate</td>
<td>Incorporate the advice and recommendations to the maximum extent</td>
</tr>
<tr>
<td>Vehicle authority</td>
<td>Involve</td>
<td>Ensure the concerns are considered and reflected in the alternatives, and provide feedback</td>
</tr>
<tr>
<td>Contractors</td>
<td>Collaborate/Involve</td>
<td>-</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>Collaborate/Involve</td>
<td>-</td>
</tr>
<tr>
<td>Research institutions</td>
<td>Consult/Involve</td>
<td>Keep informed, listened, and provide feedback</td>
</tr>
<tr>
<td>Road users</td>
<td>Involve/Inform</td>
<td>-</td>
</tr>
<tr>
<td>Road workers</td>
<td>Involve/Inform</td>
<td>-</td>
</tr>
<tr>
<td>Insurance companies</td>
<td>Inform</td>
<td>Keep informed</td>
</tr>
</tbody>
</table>

In addition, according to different leading parties in the development of driverless maintenance, three types of stakeholder engagement plans were discussed. The government leading plan requires the political power to realize clear requirements, cost compensation and contract extension for market parties. However, government institutions would face political risks. In addition, bureaucracy from government and ineffective contracts also cause problems. The market leading plan requires the market parties to evaluate market size, to develop business cases, to win political support in the competitions. However, market parties need to take legal risks and endure long process of road tests, which leads to lack of motivations. Hence, joint efforts between government institutions and market parties are necessary, combining the convenience provided by political resources and the innovations generated by technical and financial resources. But it is crucial that the cooperation is based on a similar safety culture level and a desire to move forward to higher level.

Even though pilot tests are in demand to investigate the traffic impacts of driverless maintenance, before implementation, simulation is another solution to deal with the fourth question:

*What is the expected impact of driverless maintenance on traffic safety and efficiency in dynamic highway construction zones?*
Interviews were utilized to collect necessary parameters for simulations. It is found that driverless mowing could increase the speed limit in work zones and increase the working speed of the mowing vehicle. Driverless marking painting could increase the working speed of the painting vehicle and make road users change their lanes later. However, driverless pothole repairs probably won’t make any difference. As demonstrated in Table 7.5, by simulating driverless mowing scenario, it is concluded that this driverless maintenance practice would improve traffic efficiency by increasing the average speed and reducing the average travel time and average delay of road users. However, this effect is not great. On the other hand, the implementation of driverless maintenance would increase emissions and fuel consumption of road users, which is a negative impact on environment. Fortunately, this influence is trivial as well. Both traffic efficiency and environment measures are more sensitive to the change of speed limit than that of the working speed. In addition, driverless mowing could reduce the headway and the speed difference of road users. Hence, the impact on traffic safety of road users is uncertain. Based on the results of driverless mowing simulation, accompanied traffic measures were recommended to optimize the traffic impacts. In particular, the speed limit was suggested to increase to 90 km/h and the working speed of mowing vehicle could be increased to 7 km/h.

<table>
<thead>
<tr>
<th>Traffic Impact</th>
<th>Measure</th>
<th>Increasing Speed Limit</th>
<th>Increasing Working Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Efficiency</td>
<td>Average speed</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td>Average travel time</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td></td>
<td>Average delay</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td>Environment</td>
<td>Emissions</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td></td>
<td>Fuel consumption</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Traffic Safety</td>
<td>Headway</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
<tr>
<td></td>
<td>Speed difference</td>
<td>Decrease</td>
<td>Decrease</td>
</tr>
</tbody>
</table>

The last question is important to all stakeholders because without a positive return for the whole society it makes no sense to implement driverless maintenance.

**Is it economically feasible to introduce driverless maintenance in dynamic highway construction zones?**

Based on some assumptions obtained from interviews, it turned out that driverless mowing is sensitive to the benefits generated by safety improvements because this is the major benefit. The major cost is the technical investment. When there is one severe injury or one death saved during the life cycle of the maintenance vehicle, which is 10 years, it is economically feasible to make the investment.
The outcome summarized above leads to the answer to the main research question:

*What is the feasibility of driverless maintenance in dynamic highway construction zones in terms of stakeholder involvement, traffic impacts and economic factors?*

The implementation of driverless maintenance in dynamic highway construction zones is only feasible when the joint efforts of government institutions and market parties are made based on similar and active safety culture, making the most use of political, technical, human and finance resources to satisfy the various interests of different stakeholders as much as possible. Based on microscopic simulations, driverless maintenance could improve traffic efficiency. But in order to achieve cost benefit effective, traffic safety impact of driverless maintenance is crucial. Even though it is uncertain whether driverless maintenance could improve the safety of road users, the safety of road workers would be definitely ensured. If one road worker could be saved from severe injury or death during the life cycle of the driverless vehicle, based on the preliminary CBA, stakeholders would be convinced driverless maintenance is promising and doable.

### 7.2. Scientific Contributions

#### Updated Literature Review

To begin with, a literature review of driverless maintenance development was provided in this study, which has never been conducted before. By defining two levels of automation of maintenance activity, the literature review collected and compared various maintenance products all around the world, which gave insights into the current situation of driverless maintenance development, such as the leading countries in this field, including the Netherlands, Germany, Japan, America and Russia and the most researched products, namely the driverless protection vehicle.

#### Stakeholder Analysis Framework

In the next place, a stakeholder analysis framework was constructed and applied in this study. The integration of stakeholder matrix, power-interest grid and involvement strategy could make the most use of the information collected from interviews, explaining the attributes, such as interest, alliances, resources and power, positions and engagement plan of each stakeholder. This framework was first utilized in the context of driverless maintenance as well, which served as a reference for future related researches. In addition, this framework was combined with the safety culture ladder, which measures the importance of safety in the eye of different organizations. The stakeholders were, therefore, described with an extra attribute, namely safety culture. This attribute determines whether two parties would enter into collaboration or not.

#### Decision Making System for Driverless Maintenance

Finally, a decision making system for driverless maintenance was invented. As Figure 7.1 demonstrates, based on the literature review of traffic safety and efficiency in highway construction zones, the parameter input system was built, including simulation parameters
and CBA parameters. The former contains the parameters for driverless maintenance scenarios building, such as speed limit, working speed and working period etc. The latter consists of the parameters for CBA, including potential costs and benefits and some basic assumptions for CBA. The parameter input system is integrated into the interview design, which is supposed to provide qualitative and quantitative information for the parameter system. The results of interviews are utilized to conduct simulations for driverless maintenance scenarios, investigating the impact on traffic safety and traffic efficiency, and to perform cost-benefit analysis, calculating the societal net present value of certain driverless maintenance practice and discussing the sensitive influencing factors. The combination of the results of traffic impact analysis and that of economical feasibility investigations leads to an evaluation solution to potential driverless maintenance implementation. In this study, this decision making system was merely practiced for driverless mowing scenario but it is general for the assessment of all driverless maintenance projects.

7.3. Practical Applications

Reference for Research and Investment

First of all, this study summarized the first group of potential driverless maintenance applications in the near future, including seven maintenance activities. This list could give some insights for market parties, such as contractors and manufacturers, into the fields of research and investments. Because these seven activities have already experienced the automation to various degrees, less efforts are necessary to develop them into mature driverless maintenance, compared to other maintenance activities, especially when other
countries have conduct some experiments before. In addition, as mentioned in Section 7.2, by identifying the leading countries and major research projects in the field of driverless maintenance, this study pointed out the ideal destinations for study tours for Rijkswaterstaat. It is also possible to introduce foreign innovations to the Dutch market when they are technical reliable in the future, which could be less expensive.

**Mutual Understanding**
Additionally, by conducting interviews with various stakeholder groups, this study provided the latest views from government institutions, market parties and research institutions. It turned out in the interviews that government institutions would rely on the market parties to take the initiatives to launch the development of driverless maintenance while market parties would also wait for the signals from government organizations. Without the mutual understanding, the development process would end up in a dilemma, where no party is willing to take the first step and all parties have their own excuses to remain the same situation. Based on the results of Chapter 4, Rijkswaterstaat could not only understand the expectations and requirements of other parties, market parties in particular, but also learn to find suitable partners when developing driverless maintenance.

**Accompanied Traffic Measures**
Furthermore, instead of conducting a pilot test for driverless maintenance vehicles, which is expensive and time consuming, the microscopic simulations of driverless maintenance scenarios predicted potential change of traffic conditions. Based on the results of simulations, it is recommended that accompanied traffic measures are necessary to optimize the traffic impact of driverless maintenance vehicles. For instance, in driverless mowing case, an optimal speed limit in work zones and an optimal working speed of the mowing vehicle were determined to generate the most significant positive effect on traffic efficiency and safety and the least negative effect on environment.

**Reference for CBA**
Last but not least, a rough CBA was conducted from the perspective of the whole society, which could serve as a reference for Rijkswaterstaat or other government institutions when considering implementing driverless maintenance. The basic assumptions applied and the decomposition of costs and benefits conducted in this study are also applicable when considering other driverless maintenance scenarios. This study also provided the possibility to change perspectives for cost-benefit analysis. As mentioned in Section 6.3, the expected return period of market parties was explained, which was much shorter than that of the whole society. More detailed and diverse CBA could be performed in practice based on the results of this study, in particular when Rijkswaterstaat or other parties are able to provide more data.

### 7.4. Recommendations

Driverless maintenance is still a brand-new subject, which requires further investigations. According to the interviews conducted in this study, 90% of the respondents hold positive attitude towards driverless maintenance, which proves it is promising to implement the
innovation. Based on the conclusion of this study, a series of recommendations were made for future researches.

**Database for Highway Construction Zones**
There is not a systematic database of highway construction zones in the Netherlands. The attributes of the construction zones, such as the layout, period, duration, etc. are not collected. The information could be owned by contractors, which conduct the maintenance task, but is not reported to Rijkswaterstaat. In addition, the incident data, such as crash numbers, severity etc. in highway construction zones is not available yet. Even though SWOV provides an estimated number of serious road injuries based on the combination of police registration BRON and hospital data LBZ (SWOV, 2019), the statistics deal with the incident data in all road types rather than focus on the construction zones of highway. Future researches may try to build a dedicated database for highway construction zones, including the configuration of work zones and incidents. This database could not only demonstrate the traffic impacts of highway work zones more directly but also provide more inputs for microscopic simulations and quantify the costs and benefits of driverless maintenance in a more data-based way rather than just rely on assumptions.

**International Perspectives of Driverless Maintenance**
Currently, the investigations of driverless maintenance are limited. Even though this study provided the first literature review of current driverless maintenance practices, there could be some missing projects. The reason is that the driverless maintenance projects are usually documented in local languages. In this study, projects in the Netherlands, Germany, Japan were all not described in English. In addition, driverless maintenance projects are probably documented in commercial reports rather than in published scientific paper. Hence, it requires an international perspective when searching for driverless maintenance practices. Furthermore, with the development of driverless technology, there must be increasing driverless maintenance products all around the world, even though they will probably pop out in developed countries. It is necessary to update the list of driverless maintenance practices, in order to better understand the technical development and market trends.

**Increasing Involved Interviewees**
20 interviewees participated in the investigations of this study, including members from six different stakeholder groups. However, on one hand, the interviews from road users, road workers and insurance companies were not involved. In particular, the unions of road users and road workers consist of a huge amount of members, which owns certain political power. On the other hand, the interviewees in this study mainly came from road authority, contractors and research institutions. Manufacturers and vehicle authority, which own more knowledge of driverless technology, should be further consulted in the future research.

**Diverse and Advanced Traffic Simulation**
As mentioned in Section 7.2, the decision making system for driverless maintenance was constructed, which requires microscopic simulations with VISSIM to investigate the traffic impacts of driverless maintenance scenarios. This study provided a preliminary example of driverless mowing simulation. In the future research, simulations of other maintenance
activities, such as marking painting, which involves dynamic lane closure, could be conducted. In addition, more complicated road conditions could be taken into account. For instance, the road section could be changed to three lanes or even more lanes. Not only highway but also urban roads could be investigated as well.

CBA Improvement
A rough CBA practice was presented in this study, in which the quantified benefits and costs were rather limited. A series of variables and risks was identified but not evaluated. When the database for highway construction zones are built, more parameters could be transferred into monetary value. When an increasing number of interviewees are engaged, a more complete spectrum of costs and benefits could be collected. Consequently, the CBA is expected to be conducted in a more detailed way. Additionally, it is possible to make CBA more diverse by switching the perspective of the whole society to specific parties, such as contractors and manufacturers.
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CROW. (2014). Werk in Uitvoering 96b. CROW, Maatregelen op niet-autosnelwegen (pp. 280). Ede.


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FOCUS. (1998). Remotely driven vehicle: even better this time around.


Appendix
A. Stakeholder Analysis
Definition
Stakeholder refers to individuals and organizations with a vested interest in the project area or policy promotion (WWF, 2005; Mori, 2010). Their interest will be influenced by both project activities and the consequences of project implementation or completion (WWF, 2005; PMI, 2008). In return, stakeholders can also cast influence on the objectives and achievements of projects (Macharis, 2005). Hence, it is inevitable to take into account the concerns of stakeholders to make sure the project process go smoothly and to avoid disputes and failures (Atkin & Skitmore, 2008). Stakeholder analysis is such a process to identify and analyze stakeholders’ interest and other qualitative information for better developing and implementing a project or policy (Schmeer, 2000).

Purpose
The purpose of stakeholder analysis lies in developing a strategic view of the features of stakeholders, the relationships between them as well as most important issues in their opinion (WWF, 2005). Stakeholder analysis provide policy makers and managers with a systematic assessment of different key actors, including their knowledge, interest, goals, importance etc. so that the interactions and engagement with them could be more frequent and effective (Schmeer, 2000).

In transportation field, stakeholder participation is now becoming a basic element of transport policymaking to involve the human and financial factors at the beginning and to improve the efficiency of transport strategies (Le Pira, 2015). As Booth & Richardson (2001) stated, the transport making process has developed into a a multi-agent, multi-sector and multi-modal one, in which a large scale of interest and issues is supposed to be weighted and balanced.

This research, as a feasibility study of driverless maintenance in dynamic highway construction zones, serves a part of transport policy making. The stakeholder analysis, therefore, is crucial to identify who are potentially involved in this plan and to gather the information in terms of their interest, attitudes, most cared issues. Furthermore, in this study, in order to conduct traffic impact analysis and cost benefit analysis, specific driverless maintenance scenarios were constructed. This will also stem from stakeholder analysis, in which the opinions of stakeholders serve the base of scenarios building.

Procedures
In general, stakeholder analysis consists of two important procedures, namely stakeholder identification and stakeholder assessment. The former aims to identify key stakeholders and their features, such as interest, goals, attitudes etc. The latter investigates the influence and importance of different stakeholders as well as the relationship between them. In addition, the impact of project upon stakeholders will also be analyzed (WWF, 2005).

In a more practical way, five specific steps are organized to conduct stakeholder analysis, including (1) Identifying key stakeholders; (2) Adapting the tools; (3) Collecting and recording the information; (4) Filling in the stakeholder matrix; (5) Analyzing the stakeholder matrix.
(Schmeer, 2000). Step (1) belongs to stakeholder identification while the rest of the steps are planned for stakeholder assessment mentioned above.

1. Identifying key stakeholders

In order to create a list of key stakeholders, it is recommended to answer some key questions, such as who is the user of this project, who possesses claims over resources and who is the most knowledgeable? Exploring the project from different perspective and brainstorming all possible actors are crucial in this step.

2. Adapting the tools

The stakeholder analysis is conducted with certain goals, based on which corresponding tools are supposed to be applied. Three common tools are summarized as follows:

Stakeholder Matrix

In such a matrix, different stakeholders are included with their interest, goals, resources, importance etc., depending on the research purpose. For instance, Lu (2018) also investigated replaceability (High replaceability means it is also doable when this party is replaced while low replaceability means this party must be involved) and dependency (High dependency means the decision making of this party is usually not independent and relies on others while low dependency means this party has high liberty to make decisions) degree of each stakeholder in a automated driving infrastructure study. The stakeholder matrix provides both a summary and a comparison of the features of all stakeholders.

Table A.1 Example of Stakeholder Matrix (Lu, 2018)

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>Important Resources</th>
<th>Replaceability(low/moderate/high)</th>
<th>Dependency(low/moderate/high)</th>
<th>Dependency Relationship</th>
<th>Critical Actor</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Ministry of Infrastructure and Water Management</td>
<td>Authorities on investment and policy</td>
<td>Low</td>
<td>High</td>
<td>Road authorities, vehicle authorities</td>
<td>Yes</td>
</tr>
<tr>
<td>Road authorities</td>
<td>Knowledge and authority on road infrastructure maintenance</td>
<td>Low</td>
<td>High</td>
<td>Research institutes, service providers and suppliers</td>
<td>Yes</td>
</tr>
<tr>
<td>Vehicle authorities</td>
<td>Knowledge and authority on vehicle registration, supervision and test application</td>
<td>Low</td>
<td>High</td>
<td>Manufacturers</td>
<td>Yes</td>
</tr>
<tr>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
<td>……</td>
</tr>
</tbody>
</table>

Power vs. Interest Grid

As mentioned before, stakeholders could generate impact on the project and vice-versa. The power vs. interest grid maps the interactions into a figure, with the horizontal axis displaying the interest of each stakeholder involved in the project and the vertical axis demonstrating the power each stakeholder owns to change the project. In such a grid, four quadrants are identified, in which different measures are taken to deal with stakeholders. Actors with low interest but high power should be kept satisfied otherwise they could make undesirable change to the project. For stakeholders with both high interest and high power,
it is important to conduct close management to make sure they are fully engaged and collaborated. In contrast, for stakeholder with both low interest and low power, less effort is necessary with regular monitor and generic communication. Actors with high interest but low power should be kept informed in order to prevent issues (Gudavajhala, 2017). This tool provides a more straightforward demonstration of the roles and importance of each stakeholder.

![Figure A.1 Power vs. Interest Grid](image)

**Power vs. Interest Grid**

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keep an eye (Monitor)</td>
<td>Keep them informed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Keep them satisfied</th>
<th>Manage closely</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Salience Model**

Salience model categorizes stakeholders with three different dimensions, namely power, legitimacy and urgency, reflecting the influence, rightfulness of involvement and importance of each actor respectively (Gudavajhala, 2017). As the figure shows, the greater the number is, the higher salience the stakeholder possesses.

![Figure A.2 Salience Model](image)

**Collecting and recording the information**

After stakeholders are identified and assessment tools are selected, it is necessary to get in touch with different stakeholders to acquire insightful information. Interviews and questionnaires are two common tools for information collection. Workshop could also be organized for group discussion. For instance, in a Costa Rican transport policy making process, 9 months were spent on a total of 43 personal interviews for data collection in
stakeholder analysis (Osakwe, 2010). Similarly, in order to figure out the stakeholder network in road transport information sharing system in Malta, a combination of interviews and distributions of questionnaires was carried out (Lewis, 2012), which will also be conducted in this research.

(4) **Filling in the stakeholder matrix**
The information collected from interviews and questionnaires should be categorized and processed to fill in the stakeholder matrix. It could be challengeable sometimes to translate the detailed and lengthy answers from interviewees into systematized format. Hence, it requires the researcher to take this into account when designing interview protocol, conducting interviews and taking notes.

(5) **Analyzing the stakeholder matrix**
In order to further explore the relationship between stakeholders and the project and that between stakeholders themselves, the stakeholder matrix could be analyzed with the stakeholder assessment tools mentioned above, such as power vs. interest grid and salience model. In this research, power vs. interest grid will be applied to understand the roles and importance of different stakeholders.
B. Interview Protocol
Instruction
Dear Sir/Madam, thank you for your participation! I am Ziye Huang, a master student from Delft University of Technology. This interview is part of my graduation research project, *Feasibility Study of Driverless Maintenance in Dynamic Highway Work Zones*, which is under the supervision of TU Delft and Rijkswaterstaat. This project aims to explore the feasibility of applying driverless maintenance vehicles in dynamic highway work zones, such as mowing, road cleaning etc.

In more detail, my project consists of three steps. First of all, I am interested to understand relevant stakeholders’ potential involvement when implementing such driverless maintenance plans. Secondly, I aim to build some driverless maintenance scenarios, in which some specific working conditions of driverless vehicles would be regulated. Thirdly, based on these scenarios, I will assess the impact of driverless maintenance on traffic safety and efficiency. Finally, I will conduct a cost-benefit analysis.

This interview is composed of two parts: (Part A) the investigation of stakeholders’ involvement; and (Part B) scenarios building, as following:

**Part A: Stakeholder Analysis**
In this part, you will be asked to answer some open and multiple choices questions related to your knowledge and views as a stakeholder regarding driverless maintenance. There is no correct or desirable answer so feel free and comfortable to express your thoughts and ideas.

**Part B: Scenarios Building**
In this part, you will be provided with some dynamic highway maintenance activities, which are thought to be achieved full automation in the near future. You will be invited to regulate specific working conditions of driverless vehicles in these activities based on your experience.
Part A Stakeholder Analysis

Q1. Knowledge
- Have you ever heard of “driverless maintenance” or similar concepts before?
- If so, how did you hear of it?
- How do you understand “driverless maintenance”?

Q2. Interest
- What are the potential advantages to you and your organization of “driverless maintenance”?
- What are the potential disadvantages to you and your organization of “driverless maintenance”? 

Q3. Position
- Which of the following statement best describes your opinion on “driverless maintenance”?
  (a) I strongly support it
  (b) I somewhat support it
  (c) I do not support nor oppose it
  (d) I somewhat oppose it
  (e) I strongly oppose it

Q4. Alliances & Resources & Power
If the interviewee chooses (a)(b)(c) in Q3,
- Why do you support / oppose “driverless maintenance”? 
- What conditions would have to exist for you to express this support / opposition? 
- Under what conditions would you choose (not) to support “driverless maintenance”? 
- Would you take the initiative in supporting / opposing “driverless maintenance” or would you wait for others to do? 
- Would you ally with any other persons or organizations in these actions? Which persons/organizations? 
- Would you persuade other persons or organizations to ally with you? And what do you expect their reactions? 
- Do you and your organization have financial/human/technical resources available to support “driverless maintenance”? 
- Which resources are available and how quickly can they be mobilized? 

Q5. Other Supporters / Opposes
- What other organizations, departments with an organization or persons do you think would support/oppose “driverless maintenance”? 
- What do you think they would gain from the supporting or opposing actions? 
- Which of these supporters / opposes would take initiative to do so?
Part B Scenarios Building

Supposing there is a two-lane motorway (with a shoulder), as shown in the following figure, three different maintenance activities will be conducted on it, namely mowing, marking, painting and pothole repairs.

Please describe the specific working conditions and predict the impact on driver behaviors for each activity when driverless maintenance is applied.

(1) Mowing (working only on the shoulder)

Working conditions:
- Working period (daytime/nighttime, hours, seasons, weather):
- Working speed (the speed of the work vehicle):
- Speed limit in the work zone:
- Special signs warning drivers of driverless maintenance:
- Other measures & factors:

Impact on driver behaviors:
- Impact on lane changing (speed variance, changing position, changing distance etc.):
- Impact on following mode (speed variance, distance etc.):
- Other impacts:
(2) Marking Painting (working on the side lane and keep moving)

Working conditions:
- Working period (daytime/nighttime, seasons, weather):
- Working speed (the speed of the work vehicle):
- Speed limit in the work zone:
- Is protection vehicle still necessary:
- Other measures & factors:

Impact on driver behaviors:
- Impact on lane changing (speed variance, changing position, changing distance etc.):
- Impact on following mode (speed variance, distance etc.):
- Other impacts:
(3) Pothole Repairs (working on the side lane and “stop and go”)

Figure B.4 Pothole Repairs

Working conditions:
- Working period (daytime/nighttime, seasons, weather):
- Working speed (the speed of the work vehicle):
- Speed limit in the work zone:
- Is protection vehicle still necessary:
- Other measures & factors:

Impact on driver behaviors:
- Impact on lane changing (speed variance, changing position, changing distance etc.):
- Impact on following mode (speed variance, distance etc.):
- Other impacts:

This is the end of the interview. Thank you for participating this interview! Your insightful inputs would be a great help to my research project. And I would appreciate it if you are willing to participate the second round interview, which deals with the traffic impact and cost-benefit analysis of driverless maintenance.
C. Interview Results Processing
The results of stakeholder analysis, the construction of driverless maintenance scenarios and some basic assumptions in cost-benefit analysis were all based on the results of interviews. In order to mitigate the bias of interviews, the results processing and relevant documents were explained here.

20 interviews were conducted in total. After each interview, an interview summary was sent to the interviewee. After the modifications and approval of interviewees, these summaries were made public, among which 19 interview summaries could be found below. The results of the interview with The Ministry was not allowed to quote. Therefore, the summary was not listed here. Based on the interview summaries, the answers of each interviewee to each question were summarized in a table, as Figure C.1 shows. All the sheets mentioned in this Appendix were submitted with this thesis report.

<table>
<thead>
<tr>
<th>Number</th>
<th>Organization</th>
<th>Knowledge</th>
<th>Interest</th>
<th>Part A: Stakeholder Analysis</th>
<th>Position</th>
<th>Alliances</th>
<th>Resources</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Head of teller from WAG but only concept</td>
<td>Advantages:</td>
<td>(a) Strategy support</td>
<td>(b) ERM would be our start</td>
<td>(c) Financial resources from the national government and EU</td>
<td>(d) Efficient maintenance as it reduces maintenance department of target mode</td>
<td>(e) Financial resources from the national government and EU</td>
<td>(f) Efficient maintenance as it reduces maintenance department of target mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) Possibility to provide knowledge, technology and resources</td>
<td>(c) Conditions of support</td>
<td>(d) Efficient maintenance would save</td>
<td>(e) ERM would be our start</td>
<td>(f) Efficient maintenance as it reduces maintenance department of target mode</td>
<td>(g) Efficient maintenance as it reduces maintenance department of target mode</td>
<td>(h) Efficient maintenance as it reduces maintenance department of target mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disadvantages:</td>
<td>(d) Conditions of support</td>
<td>(e) Efficient maintenance as it reduces</td>
<td>(f) Efficient maintenance as it reduces</td>
<td>(g) Efficient maintenance as it reduces</td>
<td>(h) Efficient maintenance as it reduces</td>
<td>(i) Efficient maintenance as it reduces</td>
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<td></td>
<td></td>
<td>(e) Database alignment</td>
<td>(f) Efficient maintenance as it reduces</td>
<td>(g) Efficient maintenance as it reduces</td>
<td>(h) Efficient maintenance as it reduces</td>
<td>(i) Efficient maintenance as it reduces</td>
<td>(j) Efficient maintenance as it reduces</td>
<td>(k) Efficient maintenance as it reduces</td>
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</tbody>
</table>

Figure C.1 The Answers of Each Interviewee

By comparing the answers of different interviewees within the same party, the common ideas were merged and different opinions were accumulated. By doing so, a second table was constructed, as Figure C.2 shows, demonstrating the answers according to stakeholder groups.

Figure C.2 The Answers of Each Party (1)
Based on this table, a brief version was constructed, namely the Stakeholder Matrix. And the explanation in Chapter 4 was also based on this table. In order to match the opinions with certain interviewees, the table in Figure C.1 would be searched. In scenarios building part, the results processing was similar. The answers were summarized by different stakeholder groups as well. In addition, the frequency of each answer was also identified in the table.

As Figure C.4 demonstrates, the frequency of each answer was further compared in another table, leading to the statistical results in Section 5.2.2 Scenarios Building.
Master Thesis_Interview Summary (A1)

Organization: TNO
Interviewee: A1
Interviewer: Ziye Huang
Location: Skype Meeting
Date: 09/01/2019

Background: A1 works in Department of Integrated Vehicle Safety of TNO and Department of Artificial Intelligence of Radboud University. There are two major fields he works in: (1) Artificial intelligence related to automated driving and (2) Assessment methodology for the safety automated driving system functions.

Part A Stakeholder Analysis

1. Knowledge
   A1: From a meeting with RWS I learned the concept of driverless maintenance. Driverless maintenance vehicles and driverless protection vehicles are two examples of driverless maintenance but our discussion only stays at the concept stage without very concrete practices.

2. Interest
   A1: The advantages of implementing driverless maintenance for us include the opportunity to provide knowledge, technology and resources and the enlargement of database through driverless maintenance scenarios.
   A1: At this moment I cannot see any disadvantage of driverless maintenance.

3. Position
   A1: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   A1: The reason why I strongly support driverless maintenance is that it has the potential to improve road work safety and efficiency. But if the driverless technology is not reliable enough and makes the road work less safe, I will oppose it.
   A1: We will wait RWS to initiate driverless maintenance and then express our support.
   A1: RWS will be our main client regarding driverless maintenance research. And we will cooperate with manufacturers depending on the requirements of knowledge and technology. In addition, in order to test driverless vehicles in real roads, it is necessary to apply to approval from RDW.
   A1: TNO owns technical resources for automated driving, such as functions keeping vehicles inside a lane, which could also be applied to driverless maintenance. There is a dedicated department in TNO for smart mobility but not merely for driverless maintenance. The financial budget for the research projects will be from Dutch government or European institutions. The availability and mobility of these resources will depend on the size of projects.
A1: TNO is a bridge connecting universities and the industry. But research institutions will compete for research budget. Because the car industry in The Netherlands is not large, the competition is in range of Europe.

5. Other Supporters/Opposers
A1: The only party who will oppose driverless maintenance could be the labour union. The government and the road authority will strongly support driverless maintenance.
A1: ANWB is an organisation of road users, which will also support driverless maintenance if it makes traffic more efficient.

Part B Scenarios Building

1. Mowing
A1: It is easier to change the maintenance work to night time when the traffic flow is less. But bad weather conditions are the same for driverless maintenance and normal maintenance because the vehicle is the bottleneck in this case rather than the driver because it cannot work in bad weather conditions like storming.
A1: Currently the driver needs to focus on driving and operating mowing at the same time, which could limit the speed. Therefore, driverless maintenance could make it faster. But it also depends on the speed of mowing machines.
A1: The speed limit will remain the same because it is also designed for the road users.
A1: It is necessary to remind the road users of driverless maintenance even if they might be scared about it. But they will get used to it after they find it works well hopefully.
A1: I guess some people will remain the same driving behaviors as normal and a small group of people may take more risks in driverless maintenance situation such as changing their lane later. But as for the car following mode, there will be no difference.

2. Marker Painting
A1: For working period and speed limit, the change in driverless maintenance situation is the same with mowing. The working speed change is also not sure because of the painting device. But there still needs a protection vehicle because it could protect the expensive part of the working vehicle and remind road users that the paintings are not dry yet.
A1: Similarly, a small group of road users may change their lane later but remain the same in following behaviors.

3. Pothole Repairs
A1: For working period and speed limit, the change in driverless maintenance situation is the same with mowing. The working speed will remain the same because it is necessary to wait the asphalt to be dry. But there still needs a protection vehicle because it could protect the expensive part of the working vehicle and remind road users that the asphalt are not dry yet.
A1: Similarly, a small group of road users may change their lane later but remain the same in following behaviors.
Part A Stakeholder Analysis

1. Knowledge

   A2: I have heard of driverless maintenance several times before. I once heard of it from a person from the innovation center in Helmond, who works on ITS and challenges road operators to come up with innovations. Driverless maintenance is one of the ideas from the company Road Maintenance Support. This company conducts road maintenance on the shoulder and closes the right lane and gets a fine for that. The business model of driverless maintenance could be that when the road maintenance is conducted on the shoulder, the right lane is still accessible. But the company cancels the project because of too much risk.

2. Interest

   A2: Above all, the safety of road workers will be improved by driverless maintenance. The second possibility is to improve the congestion because of no closed lane. In addition, because of the scarcity of labour, there is a need to automate the maintenance work. But I doubt driverless maintenance could do the task as good as human operators. For some simple tasks like sweeping the road, driverless maintenance could be used. And I think the driverless protection vehicle will be a priority.

   A2: For my organization, when driverless maintenance technology is mature, we can teach the students the maintenance strategy. And it could be an emerging technology in infrastructure maintenance. In addition, this topic could serve as master thesis for future research.

3. Position

   A2: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power

   A2: The reason why I choose (b) is that I support researches and business cases on driverless maintenance but I think the application should base on more tests. Only if the technology is proved to be safe and it could generate financial benefits, I will fully support it. But if it turns out unreliable and unsafe, I will oppose it.
A2: For automated driving research, we have cooperation with companies to conduct small projects. We can also obtain research budgets from national government and EU. We would also like to cooperate with larger companies if they regard driverless maintenance as a strong business case and have R&D budgets. In addition, funds from a third party like RWS are also possible.
A2: I believe the promotion of driverless maintenance is a joint effort. RWS should provide opportunities for contractors to develop driverless maintenance in the contract. The contractors need to at least get permission from road authorities to apply these vehicles. Both parties could organize study tours to other countries to learn their experience in driverless maintenance projects.
A2: As a research institution, we are open to innovation researches and would like to cooperate with RWS to develop driverless maintenance. Usually engineering consultancy companies will involve as well to make the research more applicable.

5. Other Supporters/Opposers
A2: Road authorities will have concern about the safety of driverless maintenance vehicles. They need to be convinced of the safety of the technology.
A2: The labour union may oppose driverless maintenance because of loss of job. But on the other hand, driverless maintenance could provide new jobs.

Part B Scenarios Building

1. Mowing
A2: I think the mowing vehicle should be completely redesigned or a mowing robot could directly work on the grass rather than on the shoulder. In this case, a supervisor could control several machines, which makes the maintenance much cheaper. The problem is that the mowing robot needs to be put in the work zone physically at first and when it gets stuck, someone needs to fix it.
A2: I think the working speed has no impact on traffic because it could work on the grass.
A2: I am not sure about the change of the speed limit in work zones.
A2: It is not necessary to remind the road users of driverless maintenance.
A2: Driver behaviors will remain the same as well.

2. Marker Painting
A2: The working speed could be reduced.
A2: The speed limit will remain the same.
A2: Protection vehicle is still necessary to warn road users of the maintenance.
A2: Driver behaviors will remain the same.

3. Pothole Repairs
A2: I think both the working conditions and driver behaviors will remain the same in driverless maintenance situation.
Master Thesis_Interview Summary (A3)

Organization: TU Delft
Interviewees: A3
Interviewer: Ziye Huang
Location: 2628 CN Delft
Date: 10/01/2019

Background: A3 is an assistant professor at the Department of Transport & Planning of TU Delft, whose interest includes the implications of road geometric design on road user behaviour and traffic safety, road user behaviour modelling, and safety evaluation methods.

Part A Stakeholder Analysis

1. Knowledge
   A3: I have heard of “driverless maintenance” before your research. But I have no knowledge about what is going on and what is the state of automation. I heard of this concept in a project meeting, in which someone from RWS brought forward it. Now in my understanding, driverless maintenance could mean either the automation of work itself or the automation of maintenance vehicles and both of them.

2. Interest
   A3: There is no particular advantage for my organization, TU Delft. But I can imagine some advantages for contractors because they need less workers and working could be safer. In addition, the currently used protection vehicle could be replaced in some cases, which saves costs.
   A3: If there is technical problems or it takes long to solve these problems or the problems take place more frequent, then the disadvantages are obvious. In addition, the process how the maintenance vehicle enters into motorways from lower-ranged road networks should be carefully designed. I think technology is the only concern.

3. Position
   A3: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power
   A3: The reason why I somewhat support driverless maintenance is that I can see the potential advantages such as safer and cheaper working but we need more researches to prove them. That’s why I am cautious to choose “somewhat support”.
   A3: There are two conditions necessary for me to support driverless maintenance. The most important one is that driverless maintenance can improve safety and the other is increased efficiency in terms of maintenance itself as well as traffic. Otherwise I will change my mind to oppose it.
   A3: As a research institution, TU Delft will take initiative in investigating the feasibility of driverless maintenance. The research funds come from RWS or EU projects. As in your interview list, TU Delft will also partner with RWS, RDW, the ministry, contractor, consultancy etc. to promote driverless maintenance. If other parties are relevant and
important in this plan, TU Delft will also persuade them to participate in the research by writing research proposals.

A3: The financial resources of research institutions are mainly from Dutch government and EU. Even though at this moment there is no dedicated human resource for driverless maintenance research, there are relevant professors and PhD students from T&P and 3ME Faculties researching on automated driving vehicles. However, the financial/human/technical resources are not easily available due to competitions.

5. Other Supporters/Opposers
A3: I think road authority could oppose driverless maintenance if it causes more safety problems and the contractor will also oppose if the driverless maintenance is more expensive. In addition, drivers could also oppose if traffic accidents increase.

Part B Scenarios Building

1. Mowing
A3: Driverless maintenance vehicles could work more often in the nighttime but as for seasons and weather I believe they will remain the same.
A3: I don’t think the working speed of the driverless vehicle will change because it depends on the speed of maintaining devices.
A3: The speed limit in the work zone would remain the same because it is also designed for road users.
A3: It is not necessary to remind road users of driverless maintenance because it may induce higher speed.
A3: Road users might change their lanes later because they are more confident in driverless maintenance situation.
A3: There should be no supervisor on the site unless the problems happen frequently. But it is also possible to fix the problems from a remote distance.

2. Marker Painting
A3: For working period and speed limit, the change in driverless maintenance situation is the same with mowing. As for the working speed, I think it will increase to the average traffic speed and adapt to the speed change of traffic. And it is not necessary to put a protection vehicle there.
A3: Driving behaviors will depend on the speed of maintenance vehicle and sizes. If the truck is larger than the normal one, maybe road users will change lanes in advance.

3. Pothole Repairs
A3: For working period and working speed, the change in driverless maintenance situation is the same with mowing. The speed limit will remain the same with non-driverless maintenance situation but will be lower than previous two activities. And in this case, the protection vehicle is still necessary.
A3: Road users will not change their behaviors in driverless maintenance situation.
Master Thesis_Interview Summary (A4)

Organization: Vias institution
Interviewees: A4
Interviewer: Ziye Huang
Location: Skype Meeting
Date: 21/01/2019

Background: A4 is a researcher of Vias institution, which provides advisory studies for the Federal Public Service Transport and Mobility. He works in the Department of Road Safety. Apart from accidents research and policy analysis, he also investigates some technical stuffs such as cameras.

Part A Stakeholder Analysis

1. Knowledge
   A4: I have never heard of “driverless maintenance” before. In my understanding, driverless maintenance could mean that either the maintenance itself is done by a driverless vehicle or the protection vehicle becomes driverless, which is easier to accomplish. In Belgium, I don’t know any research or field test about driverless maintenance.

2. Interest
   A4: Driverless maintenance will be safer. And the design and test of driverless maintenance vehicle could be a business for my organization.
   A4: I do not see any disadvantage of driverless maintenance.

3. Position
   A4: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power
   A4: The reason why I somewhat support driverless maintenance is that I think driverless protection vehicle is a good idea but I don’t think the maintenance vehicle has to be driverless because it is already safe now.
   A4: I will support driverless maintenance vehicle only if the task is predefined and there are human supervisors for the vehicle. But if the task is way complex, I will even oppose the driverless protection vehicle.
   A4: In Belgium, the development process of driverless maintenance could be as follows: the manufacturer takes initiatives to develop the driverless maintenance vehicle and then promote its product and persuade the government and contractors to involve in the development. After that VIAS could be employed by the government to test the vehicles. If the pilot is successful, this technology would be widely used.
   A4: The individual components for driverless vehicles already exist. Therefore, manufacturers could develop driverless maintenance vehicles on their own. It is also
possible the government will deliver some budgets for the development. But as a research institution, we won’t participate in the technical research.

5. Other Supporters/Opposers
   A4: The labour union might oppose the driverless maintenance because of job loss. But in the long term it is not a problem.

Part B Scenarios Building

1. Mowing
   A4: Driverless maintenance could be done more at night.
   A4: Working speed will remain the same.
   A4: The speed limit in the work zone will remain the same because there is no worker outside the vehicle in both traditional mowing and driverless mowing.
   A4: It is not necessary to remind road users of driverless maintenance because they may be distracted.
   A4: I am not sure about the change of driver behaviors. The only thing I am certain about is that driverless maintenance would cause distraction once drivers notice it.

2. Marker Painting
   A4: Driverless maintenance could be done more at night.
   A4: Working speed can be increased because the automated machine could do the task more precisely.
   A4: The speed limit will remain the same.
   A4: The protection vehicle is still necessary.
   A4: I am not sure about the change of driver behaviors. The only thing I am certain about is that driverless maintenance would cause distraction once drivers notice it.

3. Pothole Repairs
   A4: Driverless maintenance could be done more easily at night.
   A4: Working speed would remain the same.
   A4: The speed limit would also remain the same if no worker is outside the vehicle before.
   A4: The protection vehicle is still necessary.
   A4: I am not sure about the change of driver behaviors. The only thing I am certain about is that driverless maintenance would cause distraction once drivers notice it.
Organization: TU Delft
Interviewees: A5
Interviewer: Ziye Huang
Location: 2628 BX Delft
Date: 14/01/2019

Background: A5 is professor in Transport Policy at Delft University of Technology, faculty Technology, Policy and Management. His main interest are in long-term developments in transport, in particular in the areas of accessibility, land-use transport interaction, (evaluation of) large infrastructure projects, the environment, safety, policy analyses and ethics.

Part A Stakeholder Analysis

1. Knowledge
   A5: I have not heard of driverless maintenance before. Now in my understanding, driverless maintenance could be safer and cheaper because it saves labour cost and removes workers from risky working environment. Furthermore, driverless maintenance could be faster (I am not sure), which could reduce the maintenance period and lead to fewer delay of traffic. And maintenance could be done more frequently, which is good for the road conditions and attractive to the traffic. However, driverless maintenance could also affect driver behaviors. For instance, drivers may ignore the speed limit and speed up because there is no one in the work zone.

2. Interest
   A5: I cannot see any advantage of implementing driverless maintenance for me because it is so practical rather than academic. I suggest researches on driverless maintenance should be done by consultancy firms or other faculties of TU Delft such as Civil Engineering, 3ME etc. But if there is added academic value in the research, I will be interested as well.
   A5: If an accident involving driverless maintenance vehicle happens, resistance to driverless maintenance and even to general automated driving field will be strong. Also, some people will lose their jobs and labour unions protest against driverless maintenance but it is just a short-term disadvantage.

3. Position
   A5: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power
   A5: The reason why I somewhat support driverless maintenance is because of its potential advantages. But as a academic researcher, I will be more neutral. And if it is not safer than the current way of maintenance or it is costlier, I will oppose it.
   A5: I think RWS is the most important stakeholder, who is supposed to take initiatives because of its main interest in cost-saving and safety. Contractors will want the ministry to be clear what she expects from them so they won’t probably take the lead.
They need to know driverless maintenance could be an option or at least it is permitted. But there is also political risk for the ministry to do the experiment if accidents happen.

A5: I suggest RWS should explore the potential, cost and benefit of driverless maintenance first and find out what needs to be done for implementation. I also doubt Dutch market is not large enough. Maybe the development could be done in EU level, which will be way cheaper. But general speaking, RWS is not a very innovative organization and also it is not easy to gather all parties to the table. You need process managers to design the procedures.

A5: I think engineering consultancies which know about both road maintenance and CBA are more capable of conducting CBA for driverless maintenance. And maybe a combination of hardware engineers from Civil Engineering & 3ME and people from TPM is a option.

Part B Scenarios Building

1. Mowing
   A5: Driverless maintenance will make working in the nighttime more attractive because there will be less traffic volume and the machine could perform better than people. The seasons will remain the same because of the growing period of grass.
   A5: I expect the working speed could increase because the vehicle could avoid the obstacles faster than humans do.
   A5: The speed limit will remain the same or increase.
   A5: It is less effective to remind the road users of driverless maintenance because drivers might think they can ignore the speed limit. And if they know the maintenance is driverless, they will be curious and attracted and that could be a risk.
   A5: At the beginning, if drivers know the maintenance is driverless, they may be scared and slow down. But in the long run, they will get used to it and driver faster. And at the beginning, some drivers will change the lanes earlier but most people will remain the same behavior. And if they slow down because of curiosity of driverless maintenance, the distance between cars will be reduced. But these are just short-term effect and in the long run everything will return to normal.

2. Marker Painting
   A5: Driverless maintenance will make working in the nighttime as well.
   A5: The working speed will increase because drivers probably can paint at higher speeds less accurately.
   A5: The speed limit change will depend on the speed change of the driverless maintenance vehicle. If the speed variance between the maintenance vehicle and road users is way smaller, the speed limit could increase.
   A5: Protection vehicle could be still necessary to warn road users of the maintenance.
   A5: For driver behavior change, I think it is the same with mowing situation.

3. Pothole Repairs
   A5: Driverless maintenance will make working in the nighttime as well.
   A5: I am not sure about working speed change because I don’t have related knowledge about the technology.
A5: I think the speed limit will remain the same.
A5: The protection vehicle is necessary to warn the road users of the maintenance.
A5: For driver behavior change, I think it is the same with mowing situation.
Master Thesis_Interview Summary (A6)

Organization: TU Delft
Interviewee: A6
Interviewer: Ziye Huang
Location: 2628 BX Delft
Date: 10/01/2019

Background: A6 teaches transport policy analysis at Delft University of Technology, faculty Technology, Policy and Management. His main interest is in long-term developments in transport, the environment, cost-benefit analysis and the practice of ex ante transport policy evaluation studies.

Part A Stakeholder Analysis

1. Knowledge
   A6: I haven’t heard of “driverless maintenance” before your research. But now in my understanding, driverless maintenance is a technology which is cost-saving and causes less safety problems in maintenance work.

2. Interest
   A6: There is no particular advantage for my organization, TU Delft. But driverless maintenance could be an interesting research topic for some faculties.
   A6: I will advise the road authority to conduct more researches on the cost-benefit analysis of driverless maintenance technology and the advantage of having less people involved in this technology considering the labour shortage. The road authority may not necessarily conduct CBA themselves but they could assign this task to other parties such as research institutions.
   A6: The potential disadvantage of driverless maintenance is that the benefit of this technology is not high but the cost is high. For instance, there should be more IT people involved. But in the perspective of the whole society, I cannot see any disadvantage. In my opinion, road users don’t bother whether the maintenance is driverless or not.

3. Position
   A6: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   A6: The reason why I strongly support driverless maintenance is that it could result in cheaper maintaining with higher benefits. But I said it “could” rather than it “will” and that’s why I support more researches on it. If the benefit is really higher than the cost, I will support this plan, otherwise I will change my mind to oppose it. But I am optimistic about driverless maintenance because it could save more personnel and it could be safer.
   A6: There are two main stakeholders who are important: the road authority that gives money for maintenance and the market party that does the maintenance. The
initiative to promote driverless maintenance lies in road authority, who should be open to innovation. But road authority does not care how is the maintenance work done as long as it is done as safe as possible and as cheap as possible.

A6: As a research institution, TU Delft will also rely on the funds from government to conduct research on driverless maintenance. And RWS should be the bridge between research institutions and market parties, which could collaborate to put the technology to the road, such as conducting some pilots. But on the other hand, RWS is a bit conservative, who is more willing to follow the current practices. Driverless maintenance, as an innovative practice, is a big step for RWS, who is afraid of failure and errors.

A6: For research institutions financial resources come mainly from Dutch government and EU as well. Human resources such as professors and PhD students are also included in the funds and grants. In addition, universities deal with education, fundamental research and market-funded research. Other research institutions such as TNO only focus on market-funded researches to win projects of Dutch government and EU. Hence, there are both competition and cooperation between universities and other research institutions.

5. Other Supporters/Opposes
A6: According to me, The Ministry, road authority and RDW are important in implementing driverless maintenance. In addition, ANWB, the group of car users, can be also important and should be informed. This organization deals with education of car users and marketing activities. If it could be convinced that driverless maintenance is safer and cheaper, it won’t oppose this plan. Even though ANWB is not a deciding party but once it is annoyed, it could oppose.

Part B Scenarios Building

1. Mowing
A6: It is easier for driverless maintenance vehicles to work in the nighttime, in the weekend and in bad weather conditions.
A6: I think the working speed will remain the same because the driverless maintenance vehicle may lose some flexibility in working even though it could gain some speed in moving.
A6: The speed limit of work zones will remain the same.
A6: I don’t think it is necessary to make road users realize the maintenance is driverless.
A6: I cannot see the difference of driver behaviors between non-driverless situation and driverless maintenance situation.

2. Marker Painting
A6: For working period, working speed, speed limit, the change in driverless maintenance situation is the same with mowing. But there still needs a protection vehicle because the it is necessary to remind road users that the paintings are not dry yet. But if the protection vehicle only functions to protect the driver of the working vehicle, it is no longer necessary in driverless maintenance situation.
A6: Driver behaviors will remain the same as normal.
3. Pothole Repairs

A6: For working period, working speed, speed limit, the change in driverless maintenance situation is the same with mowing. The protection vehicle is still necessary if road users should wait the fixed pothole to be dry.

A6: Similarly, driver behaviors will not change.

PS

For cost-benefit analysis, it is necessary to know the working mechanism of driverless maintenance vehicles to make cost evaluation. In addition, try to obtain some cost numbers from interviews and literature.
Master Thesis_Interview Summary (B1)

Organization: Rijkswaterstaat
Interviewees: B1
Interviewer: Ziye Huang
Location: 2288 GK Rijswijk
Date: 15/01/2019

Background: B1 works on the field of safety culture and safety management system in RWS, including traffic safety, worker safety, construction safety, social safety, high water protection etc. PDCA cycle is the major way of working and RWS currently stays mostly at the stages of Plan and Do. But they never check if things are done and efficient or not.

There are five steps in the safety culture: “do nothing” --- “incident driven” --- “cost-benefit driven” --- “proactive” --- “generative safety”. RWS is somewhere between “incident driven” and “proactive” and tends to move forward to “generative safety”. The main stream within RWS is “cost-benefit driven”.

Part A Stakeholder Analysis

1. Knowledge
   **B1**: I have heard of driverless maintenance before. The most dangerous part in road working is placing and removing cones and there are already some vehicles, which can do it automatically but is not driverless yet. This vehicle could improve the safety of workers.

2. Interest
   **B1**: Driverless maintenance is safer. It is also possible to improve efficiency and save costs in driverless maintenance situation.
   **B1**: There is possibility of failure for the technology.

3. Position
   **B1**: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   **B1**: The reason why I strongly support driverless maintenance is because I value every life but the technology should be reliable. Therefore, more researches should be conducted, especially in uncomfortable conditions.
   **B1**: RWS gives each contractor a five-year contract and nothing innovative is paid by RWS. Therefore, contractors tend to choose the cheapest rather than the safest way to do the job.
   **B1**: We don’t want safety in the bid because safety is the basic rule so don’t argue with that. Otherwise those contractors who bid with lower price but lower safety can still win. Currently there is no trigger to do the job as safe as possible. Instead, keeping it safe, it is better to make it as cheap as possible. That’s why driverless maintenance is not picked up by contractors now.
**B1:** Contractors tend to underestimate the risk. Usually the main contractor knows the risk but subcontractors know less about the risks.

**B1:** We offer a functional contract, in which the desired outcome is described but the way of working is not restricted. This aims to let contractors choose the most economic way to do the job. It is difficult to change. But innovation could gain some points or cost reduction in the evaluation procedure.

**B1:** There is an innovation cluster in RWS, which could stimulate the market parties (contractors, manufacturers etc.) to develop new technology by discussing with them and delivering budgets. Maybe a longer term contract like 10 years rather than 5 years could make contractors more willing to invest on driverless maintenance. But on the other hand, it is difficult for contractors to put the research outcome into practice. One reason is that safety in the bid is not enough stressed. The other reason is that contractors are sometimes conservative, who rely only on proved-technology.

**B1:** RWS has annual 6.000.000.000 euro budgets. Therefore, in the process of research development, financial resources are not a problem.

**B1:** It takes some time to change the regulations and laws for driverless maintenance. But it is up to RWS to make the regulations rather than the ministry.

### Part B Scenarios Building

1. **Mowing**
   
   **B1:** There is no big difference in working period.
   
   **B1:** There is no need to reduce the working speed for safety reasons in driverless maintenance situation. I think the working speed would increase.
   
   **B1:** The speed limit in work zones will be higher.
   
   **B1:** It is not necessary to remind the road users of driverless maintenance because drivers could be confused.
   
   **B1:** Driver behaviors will remain the same because road users won’t realize the maintenance is driverless. But if they know the maintenance is driverless, they could change their lanes later because the risk is reduced.

2. **Marker Painting**
   
   **B1:** Driverless maintenance could be done at the nighttime more easily.
   
   **B1:** The working speed can be higher.
   
   **B1:** The speed limit can be higher as well.
   
   **B1:** Protection vehicle is still necessary to warn road users of the maintenance because red cross is not enough.
   
   **B1:** For driver behavior change, I think it is the same with mowing situation.

3. **Pothole Repairs**
   
   **B1:** I think there is no difference in working period and working speed.
   
   **B1:** I think the speed limit will be higher.
   
   **B1:** The protection vehicle is necessary to warn the road users of the maintenance.
   
   **B1:** For driver behavior change, I think it is the same with mowing situation.
Master Thesis_Interview Summary (B2)

Organization: Rijkswaterstaat
Interviewees: B2
Interviewer: Ziye Huang
Location: 2288 GK Rijswijk
Date: 11/01/2019

Background: B2 is the innovation manager of Rijkswaterstaat, who focuses on both infrastructure and mobility fields.

Part A Stakeholder Analysis

1. Knowledge
   B2: I have heard of driverless maintenance before from people from construction companies, who think driverless maintenance could improve the work safety. In my understanding, driverless maintenance means some parts of the work or all of it could be done by vehicles which are driven without a driver.

2. Interest
   B2: There are advantages for both RWS and construction companies and the whole society. First of all, the work safety could be improved. In the next place, considering the costly safety measures, driverless maintenance could save more money in terms of safety measures. In addition, driverless maintenance could also reduce the labour cost.
   B2: In the short run, there could be people losing their jobs and the driverless technology itself is not flexible.

3. Position
   B2: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   B2: The reason why I strongly support driverless maintenance is that it has the potential to be safer and cheaper. A third reason is the noisy and polluting working environment is bad for workers’ health. Driverless maintenance is beneficial to them.
   B2: Only under driverless maintenance situation is safety, health and cost-saving better than that under normal situation, I will support driverless maintenance. At this moment, I guess driverless maintenance is not as good as non-driverless maintenance in these aspects. But I believe that in the future the society should enhance the development of driverless maintenance. I will withdraw my support if driverless maintenance is more expensive and the safety and health are not improved.
   B2: I think RWS should initiate to encourage the development of driverless maintenance and set tables for parties to join. And it is good that RWS partners with construction companies and research institutions to discuss the development. RWS could also persuade provinces and municipalities to participate in the investigation. For instance, RWS could announce that all the maintenance work should be done
driverlessly and it is the contractor to make the decision. Or RWS could deliver budgets to research institutions and companies to develop driverless maintenance technology. And if driverless maintenance is on the agenda of RWS, it could organize dedicated teams working on it.

**B2:** If RWS would like to launch a innovative project such as driverless maintenance, financial resources are easily available but human resources are difficult to be organized.

5. **Other Supporters/Opposers**

**B2:** I think every party would support driverless maintenance. Even if some people will lose their jobs due to driverless maintenance, they will find other jobs in the construction sector.

Part B Scenarios Building

1. **Mowing**

**B2:** 15 or 20 years ago, a friend of mine in Belgium owned a driverless mowing machine in his garden and it worked very well. It cost 2,000 euro at that time.

**B2:** If driverless maintenance is applied, the maintenance work could be done 24 hours a day. But it also depends on the supervisor, who is necessary to keep an eye on the maintenance vehicle from a remote distance probably.

**B2:** The working speed could increase.

**B2:** The speed limit will remain the same because it is also designed for the road users.

**B2:** It is not necessary to remind the road users of driverless maintenance.

**B2:** I don’t think driverless maintenance will affect driver behaviors. Drivers won’t feel scared about driverless maintenance but politicians will because they are worried about safety issues.

2. **Marker Painting**

**B2:** For working period, working speed and speed limit, the change in driverless maintenance situation is the same with mowing. If we can add the absorber right behind the driverless mowing vehicle, it may be not necessary to put a protection vehicle.

**B2:** Similarly, the driver behaviors will remain the same.

3. **Pothole Repairs**

**B2:** For working period, working speed and speed limit, the change in driverless maintenance situation is the same with mowing. In addition, the increase in working speed will have positive impact on traffic capacity because you won’t wait until nighttime and you prefer to fix the pothole as soon as possible. Besides, the protection vehicle is not necessary.

**B2:** Similarly, the driver behaviors will remain the same.
Master Thesis Interview Summary (B3)

Organization: Rijkwaterstaat
Interviewees: B3
Interviewer: Ziye Huang
Location: 3526 LA Utrecht
Date: 17/01/2019

Background: B3 is a traffic engineer, who works on traffic management part of RWS. He once dealt with the misuse of red crosses on highways.

Part A Stakeholder Analysis

1. **Knowledge**
   
   **B3:** I have heard of driverless maintenance before. There are two sources within RWS from which I learned the future possibility. Also from the conversation and conferences with colleagues from other countries and regions like Germany, Flanders and UK, this concept was discussed. In my understanding, driverless maintenance refers to the self-driving maintenance vehicle. And good road conditions are necessary as support, such as clear lines.

2. **Interest**
   
   **B3:** The advantage mainly includes improved safety.
   
   **B3:** The disadvantage comes from the immature technology, which could fail.

3. **Position**
   
   **B3:** I am somewhere between (a) I strongly support driverless maintenance and (b) I somewhat support driverless maintenance, depending on the benefits from pilot tests. If it turns out with lots of benefits, I will choose (a).

4. **Alliances & Resources & Power**
   
   **B3:** I think driverless maintenance is not the core business of RWS and we don’t need to take initiatives to promote it. But we will follow the development of the technology. I think market parties are supposed to take initiatives to develop the technology. If the market develops this innovation project, we will stimulate it.
   
   **B3:** I have colleagues dealing with innovation issues. They could discuss with market parties such as contractors about the plan of driverless maintenance development. This conversation could also include research institutions. Vehicle suppliers will involve in later process when the requirements are determined.
   
   **B3:** In the beginning phase, we need to narrow the distance between RWS and market parties. And combined efforts are necessary to investigate the possibilities.
   
   **B3:** Financial resources are not easily available in RWS. Politicians should be convinced that driverless maintenance is beneficial to traffic safety. A dedicated working team may be organized to involve in the research.

5. **Other Supporters/Opposes**
B3: I cannot see any major opposition to driverless maintenance. But the bottleneck is that it is always not easy to change something. You need lots of data from pilots in different situations to convince people.

Part B Scenarios Building

1. **Mowing**
   - **B3**: Driverless maintenance could be done more at the nighttime if the lighting conditions are good.
   - **B3**: Working speed of driverless maintenance will remain the same in order not to confuse the road users.
   - **B3**: The speed limit in work zones will remain the same.
   - **B3**: It is not necessary to remind the road users of driverless maintenance because drivers could be confused.
   - **B3**: Driverless maintenance vehicles should look the same with normal maintenance vehicles. Therefore, driver behaviors could remain the same.

2. **Marker Painting**
   - **B3**: For working period, working speed and speed limit, the change in driverless maintenance situation is the same with mowing.
   - **B3**: Protection vehicle is still necessary to warn road users of the maintenance.
   - **B3**: For change of driver behavior, I think it is the same with mowing situation.

3. **Pothole Repairs**
   - **B3**: For working period, working speed and speed limit, the change in driverless maintenance situation is the same with mowing.
   - **B3**: Protection vehicle is still necessary to warn road users of the maintenance.
   - **B3**: For change of driver behavior, I think it is the same with mowing situation.
Master Thesis_Interview Summary (B4)

Organization: Rijkswaterstaat
Interviewees: B4
Interviewer: Ziye Huang
Location: 3011 XD Rotterdam
Date: 25/01/2019

Background: B4 is my supervisor from Rijkswaterstaat. He works in The Department of Large Projects and Maintenance and he is an expert in the field of highway work zones safety.

Part A Stakeholder Analysis

1. Knowledge
   B4: I have heard of driverless maintenance before. I am a member of the international group of road safety and road worker safety. One of the issue is how can we make the work zones safer for both road workers and road users. When there are less people to be hit in driverless maintenance situation, work zones will be safer. In the group, we discuss the development trend of road safety measures and the case in which the safety could be improved. I think lots of government institutions and building companies are already aware of driverless maintenance and welcome this new development.

2. Interest
   B4: Driverless maintenance is safer because no road worker will be hurt in an accident. In addition, I think people will get used to driverless maintenance soon.

3. Position
   B4: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   B4: The reason why I strongly support driverless maintenance is that I think it will be successful and also necessary. In driverless maintenance situation we don’t need workers, which will be safer and maybe cost benefit effective as well.
   B4: When the technology is not fully developed or after tests lots of incidents data are collected, I think this will delay the application of driverless maintenance. But I don’t think this will stop the development. The tendency to promote driverless maintenance is very strong. So I won’t change my mind of supporting driverless maintenance. As for other parties, I don’t see any huge problems.
   B4: I think market parties are taking initiatives to develop driverless maintenance systems. And government institutions welcome the new innovation. When you have the equipment and you can install some units to make it become driverless, that will be cheaper. I also think the national government is the leading role to promote driverless maintenance. And if there are projects from companies that inspire us, the government will consider delivering budgets to them.
**B4:** RWS may encourage the market parties to develop driverless maintenance by conducting small scale projects and doing tests and experiments on simple maintenance tasks. But we also need approval from RDW to test the driverless maintenance vehicle on roads.

**Part B Scenarios Building**

1. **Mowing**
   
   **B4:** Night time would be the best time to do the maintenance when driverless maintenance is implemented.  
   **B4:** The working speed might increase.  
   **B4:** The speed limit in work zones will remain the same.  
   **B4:** It is not necessary to remind the road users of driverless maintenance because drivers will be distracted.  
   **B4:** Driver behaviors will remain the same because road users won’t realize the maintenance is driverless. But if they know the maintenance is driverless, in the long run they will also get used to it and keep the same driver behaviors. This is my opinion, but you need to test it in road tests or simulators.

2. **Marker Painting**
   
   **B4:** Night time would be the best time to do the maintenance when driverless maintenance is implemented.  
   **B4:** The working speed depends on both the device and the vehicle so I am not sure about the change.  
   **B4:** The speed limit in work zones will remain the same.  
   **B4:** It is still necessary to put a protection vehicle behind the working vehicle.  
   **B4:** Driver behaviors will remain the same because road users won’t realize the maintenance is driverless. But if they know the maintenance is driverless, in the long run they will also get used to it and keep the same driver behaviors. This is my opinion, but you need to test it in road tests or simulators.

3. **Pothole Repairs**
   
   **B4:** For both working conditions and driver behaviors, I don’t see any difference.  
   **B4:** I think for this activity it takes a long time to make it driverless maintenance and also it makes no big difference whether it is driverless or not. Instead, driverless mowing and protection vehicle are the main focuses of market parties.
Master Thesis Interview Summary (C1 & C2)

Organization: Royal BAM Group
Interviewees: C1 & C2
Interviewer: Ziye Huang
Location: 4815 NG Breda
Date: 18/01/2019

Background: C1 is a traffic manager in BAM. C2 works in the field of traffic management in BAM as well and he is responsible for large maintenance work for RWS and municipalities.

Part A Stakeholder Analysis

1. Knowledge
   C1: I have heard of “driverless maintenance” before. I have a director who supports a project of driverless maintenance and his goal is to investigate what we can do for the development of driverless maintenance as contractors.
   C2: BAM has a big program named “Safety First”. Road work is usually in open/semi-open work zones, where there is increasing risk of incidents. Eliminating workers from work zones is a high priority. We always tend to make things into automation in order to relieve the physical stress on people. For instance, the automation of placing and removing traffic cones is investigated. But it is a costly and time-consuming process. So yes, we have heard of driverless maintenance before but it is not our daily business.

2. Interest
   C2: Driverless maintenance could be safer, which we contractors care a lot.

3. Position
   C2 & C1: We both choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   C2: The driverless maintenance project mentioned before is a combined effort. In that project, we rely on other partners, who buy vehicles from manufacturers and make some changes on them, to develop the technology. But I have never seen actual innovations in the past couple of years.
   C2: RWS is supposed to take initiatives to promote driverless maintenance rather than wait for market parties. Because driverless maintenance is expected to be expensive and market parties hesitate to invest unless it is legal.
   C2: The financial resources for our innovation come from our company. We will invest on research which will cash out in five years because lots of things will change in five years. But the market of driverless maintenance is small and due to the restriction of European Law and contracting law, the R&D budget for driverless maintenance is rather little. If RWS has a driverless maintenance program, then it is possible to win the research budgets.
C2: I think RWS should not be the leader of driverless maintenance development. RWS is expected to encourage rather than control the development. Otherwise bureaucracy will generate negative impacts. In addition, hardware development is usually not the core business of government.

C2: We will not be the leader either. Instead, the society will be the leader. From the safety point of view, the society will support driverless maintenance. The public will influence the political decision, which is the driving force of driverless maintenance development.

C2: It is possible to emphasize the importance of innovation in the process of tendering to encourage the development of driverless maintenance. But usually it is hard to measure the degree of innovation. On the other hand, in terms of the duration of contract, the longer the contract is, the more attractive for us to make investments on innovations.

5. Other Supporters/Opposes
C2: Workers can hold negative attitude toward driverless maintenance due to loss of job. But they should consider to make themselves more flexible rather than do a job as long as possible. In addition, the building and cleaning of driverless maintenance vehicle can create new jobs.

Part B Scenarios Building

1. Mowing
   C1: Working period won’t change.
   C2: Working speed would increase.
   C2: The speed limit in work zones could also increase.
   C2 & C1: The size of the driverless maintenance could also be reduced due to no driver, therefore would be cheaper.
   C2: The regulations of road working are mainly designed considering the labor safety. Once the maintenance is driverless, safety measures could also be reduced.
   C2: The appearance change of driverless maintenance will cause distraction of road users. But the change of driver behaviors is a personal factor, which I am not sure about.
   C1: In the beginning, I expect there would be more accidents because road users would be attracted and slow down.

2. Marker Painting
   C1: Working period won’t change.
   C2: Working speed depends on both the speed of the vehicle and the speed of the painting device.
   C2: It is still necessary to put a protection vehicle behind, which should be driverless as well, in order to forgive the mistakes of road users.
   C1: In the long term, road users are less likely to adapt their speed to the speed limit and willing to accept more risks.

3. Pothole Repairs
C2 & C1: For working period, working speed and the speed limit, no change will take place.
C2: The protection vehicle is more necessary.
C1: Similarly, in the long term, road users are less likely to adapt their speed to the speed limit and willing to accept more risks.
C2: The investment on driverless maintenance vehicle is large. But in the long run it will be cheaper because it saves labor cost and the protection measures could be reduced.
Part A Stakeholder Analysis

1. Knowledge
   **C3:** I have heard of “driverless maintenance” before because I am a member of a board, in which “driverless maintenance” is discussed. In my opinion, driverless maintenance includes three aspects: driverless road users, driverless protection vehicles and driverless maintenance vehicles.

2. Interest
   **C3:** The advantages of driverless maintenance to my organization lie in that both working safety and working efficiency will be improved.
   **C4:** Especially in The Netherlands we are experiencing a shortage of labour, therefore, driverless maintenance could improve this situation.
   **C3 & C4:** The biggest disadvantage of driverless maintenance for us is that the technology itself is not mature and reliable yet. Once it becomes a proved-technology, there will be no disadvantage for us except for additional investments on technical human resources such as skills training.

3. Position
   **C3:** We choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   **C3:** The reason why I strongly support driverless maintenance is that it could improve road work safety and efficiency but the technology must be reliable and bring financial benefits. However, we won’t initiate to support this plan unless the client, RWS, states clearly in the bid book or contract that they want the maintenance work done in a driverless way.
   **C3:** In addition, dedicated law and regulations regarding driverless maintenance should be issued to promote the application of driverless maintenance.
   **C4 & C3:** There is an organization named Bouwend Nederland (Dutch Builders), in which 40 contractor companies are involved to discuss important issues of the industry. Driverless maintenance is also one of these topics. The board mentioned before is a vakgroep of this organization. We are trying to persuade and attract more contractors and even manufacturers to participate in it. When the whole industry
enters into cooperation, driverless maintenance could be possible. Otherwise, there is no motivation for contractors to make investments on driverless maintenance because of fierce competition.

C3: Currently we don’t have any financial/human/technical resources available to support driverless maintenance. Only when RWS is determined to promote this working method and related law and regulations are issued, the investments are worth considering.

5. Other Supporters/Opposes
C3: I think manufacturers will also support driverless maintenance because the innovative products could provide benefits for them.

Part B Scenarios Building

1. Mowing
C4: Driverless maintenance vehicles could work in bad weather conditions and full dark environment, which is dangerous for a driver.
C3: I think the working period (daytime/nighttime, seasons and weather) for driverless maintenance won’t change. It is regulated that the maintenance work should be done with lights so even if the driverless maintenance vehicle could work in bad environment, it should be allowed by the law or regulations at first.
C4 & C3: The working speed of the driverless vehicle will increase.
C3: The speed limit in the work zone could increase from 70 km/h to 90 km/h. But if the road users also use driverless cars, the speed limit could be higher.
C3: It is necessary to set up signs to remind road users of driverless maintenance.
C4: Maybe road users may be scared at the beginning, but they will get used to it soon after they find it works well.
C3: There are still supervisors necessary for the driverless maintenance vehicles. And the location of the supervisor depends on the working efficiency. If there is a remote control room, in which the supervisor is able to oversee the working situations of a number of driverless maintenance vehicles, that will be more efficient.
C4: Considering the fear of road users to driverless maintenance vehicles, they could be more cautious and change their lane earlier. But for the car following mode, we don’t think there will be any difference in driverless maintenance situation.

2. Marker Painting
C4 & C3: For working period, working speed, speed limit, the change in driverless maintenance situation is the same with mowing. But there still needs a protection vehicle because the it is necessary to remind road users that the paintings are not dry yet.
C4 & C3: Similarly, road users will change their lane earlier but remain the same in following behaviors.

3. Pothole Repairs
C4 & C3: For working period, working speed, speed limit, the change in driverless maintenance situation is the same with mowing. The protection vehicle may be not necessary if the pothole repair vehicle is equipped with a truck-mounted attenuator
as a crash absorber and buffer. And considering pothole repair is a “stop and go” situation, the warning signs should in a larger size.

**C4 & C3:** Similarly, road users will change their lane earlier but remain the same in following behaviors.

**C4 & C3:** For mowing, marker painting and pothole repairs, the location of maintenance vehicles and the size of the vehicles may also make difference to driver behaviors.
Master Thesis_Interview Summary (C5)

Organization: VolkerInfra
Interviewees: C5
Interviewer: Ziye Huang
Location: 4131 NJ Vianen
Date: 18/01/2019

Background: C5 graduates from Transport & Planning of TU Delft and works in the field of traffic management in VolkerInfra.

Part A Stakeholder Analysis

1. Knowledge
   C5: I have heard of “driverless maintenance” before your research. It’s very upcoming. I know the robot mowing machine already exists. We also have driverless asphalt pavement machine but this machine doesn’t work when there is traffic. If the driverless maintenance vehicle is only applied in a closed work zone, then RWS has no saying. But the contractor needs to prove the safety of these vehicles. Only if there is traffic passing by, RWS will be involved in the application of driverless maintenance.

2. Interest
   C5: Driverless maintenance could be safer and more efficient as advantages to my organization.
   C5: But if the driverless maintenance fails, it will be a threat to the safety, which is a disadvantage.

3. Position
   C5: I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   C5: The reason why I strongly support driverless maintenance is that the protection measures are really expensive, which could be not necessary any more in driverless maintenance situation. But once something goes wrong and there is no enough protection measures, the accident would be fatal and bad for our reputation. In spite of this, I am optimistic about driverless maintenance.
   C5: The contractor will try to develop driverless maintenance technology when stimulated by RWS. For instance, if this technology could improve safety or is eco-friendly, then the contractor could gain price reduction and win the project. It is also possible that the contractor could receive some research budgets from RWS after they win the project. But the contractor needs to prove that he can make and use the technology while bidding even though it is not necessary to have the machine at that time.
C5: Both the contractor and the manufacturer could be the leader in the development of driverless technology, depending on the pull or push market model. In addition, RWS could be the leader as well. These parties could also collaborate.

C5: Once the driverless maintenance is on the agenda of my company, there will be financial/human/technical resources organized for the development. The availability and mobility of these resources depend on the determination of my organization.

Part B Scenarios Building

1. Mowing
   C5: Working period of driverless mowing won’t change.
   C5: Working speed would increase (not sure) in driverless maintenance situation to reduce the speed variance with the traffic.
   C5: The speed limit can be increased compared to traditional mowing.
   C5: It is not necessary to remind road users of driverless maintenance.
   C5: Driver behaviors will basically remain the same. But if the driverless maintenance vehicle increases the speed, road users will notice the speed variance later and therefore change the lane later as well.

2. Marker Painting
   C5: Working period will remain the same.
   C5: Working speed would increase as mowing.
   C5: The speed limit depends also on the speed variance between working vehicle and the traffic.
   C5: Protection vehicle is not necessary for driverless maintenance because it is mainly designed for workers rather than road users. But we can add the absorber behind the working vehicle. Or a driverless protection vehicle is an option.
   C5: The change in driver behaviors is the same as mowing situation.

3. Pothole Repairs
   C5: Working period will remain the same.
   C5: Working speed will remain the same as well because it depends on the speed of device and also the time to dry.
   C5: The speed limit will remain the same because the vehicle stops and creates the largest speed variance.
   C5: The protection vehicle is still necessary.
   C5: Driver behaviors will remain the same as well.
Master Thesis_Interview Summary (C6)

Organization: VolkerInfra
Interviewees: C6
Interviewer: Ziye Huang
Location: 2031 CC Haarlem
Date: 17/01/2019

Background: C6 is a maintenance manager for about 20 years. He mainly deals with DBFM projects. He has been involved in three highway projects, one railway project and one lock gate project. He is responsible for the maintainability and availability of the road for the public during the construction phase and maintenance phase, which varies from 10 to 26 years.

Part A Stakeholder Analysis

1. Knowledge
   C6: I have heard of “driverless maintenance” before your research. We have done two “driverless maintenance” practices. The first one was during the HSL Project, in which the grass on banksments need trimming. In The Netherlands, mowing has to be done twice every year and it is costly. We applied a robot to do the mowing with supervisors keeping it in sight. It was a successful test. Another practice was mowing on A12 highway with a robot as well, which was also successful. Another possible driverless maintenance I can come up with is cleaning and removing the juice and body of the animal from the asphalt with a driverless vehicle without closing a lane.

2. Interest
   C6: One of the advantages is that up to now it is difficult to tell the mowing robot where the grass is. Secondly, extra safety measures are necessary to make sure the robot won’t enter the road itself. In addition, the robot is too small to collect the grass it mows. Furthermore, if something goes wrong, you still need supervisors.

3. Position
   C6: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power
   C6: The reason why I somewhat support driverless maintenance is that the technology is not reliable enough to be used everywhere.
   C6: As a contractor, we are very passive. Usually we applied the mowing machine with a driver and we have the alternative to do the job at night. Therefore, we just wait the market parties (manufacturers) to develop the vehicles or machines and conduct field tests and then send them feedback.
   C6: The mowing robot is not cheaper than the traditional way because of lower working speed and necessary supervision.
   C6: We apply for permission from RWS and the Highway Agency to test the mowing robot. I think RWS will cooperate in the development of driverless maintenance later.
But I don’t think RWS will take initiatives to act. Instead, manufacturers will play the leading role if they see the demand. Based on my experience, we contractors won’t invest on or participate in the technology development because it is not our core business.

C6: Within the company we have innovation budgets and organizations but they are only used for development within the company. We seldom invest on a third party for technical development unless it is necessary for the project.

C6: The traditional mowing cost is 4.50 Euro per 100 square meters.

Part B Scenarios Building

1. Mowing
   C6: Driverless maintenance will be conducted at the nighttime as now. So no changes will take place.
   C6: I think at the beginning the working speed will be slower, which will be 50%-80% of the current speed of 2 km/h.
   C6: The speed limit in the work zone will remain the same.
   C6: It is not necessary to remind road users of driverless maintenance.
   C6: The cost of traditional maintenance cost is 120-150 Euro per hour. And the driverless mowing cost is 90 Euro per hour, which is much cheaper. But mowing won’t last long and if you look at the cost per 100 square meters, there is hardly difference between traditional mowing and driverless mowing.
   C6: Driverless maintenance has no impact on driver behaviors because road users don’t know the maintenance is driverless.

2. Marker Painting
   C6: There are two scenarios in marker painting. First, if the asphalt is new, the life cycle of the marker is the same with the asphalt. So we will paint the marker in the last hour of laying asphalt. In this case (80%), we will do the job at the nighttime and there will be no traffic at all. Therefore, working conditions for driverless maintenance is totally the same. Another scenario (20%) is that the marker needs to be repainted but the asphalt is still good. It will still be done at night and the working conditions for driverless maintenance will still be the same.
   C6: Marker painting is a labor intensive task. Driverless maintenance is not beneficial for traffic safety in this activity because it is already very safe now. The major benefit is the labor cost could be reduced.

3. Pothole Repairs
   C6: In The Netherlands, when there is a pothole, it is only allowed to repair it between 10am and 2pm and after 8pm.
   C6: There are three kinds of vehicles applied in pothole repair, including the vehicle cutting the old asphalt, compacting vehicle and asphalt vehicle. I think a combination of these three kinds of vehicles is much more worth researching than a driverless maintenance vehicle for this activity.
   C6: For three vehicles, the cost is roughly 300 Euro per hour. Once they are combined, the cost could be 120 Euro per hour. Usually in the Netherlands, the cost
of the combination of the machine and a driver is 70 - 120 Euro per hour and the cost of workers is 30 - 50 Euro per hour.

C6: For mowing, marker painting and pothole repairs, I think driverless maintenance will be safer. But it is already safe for these three activities and the intelligent maintenance vehicle is expensive. Therefore, it could be not cost benefit efficient to apply driverless maintenance.
Master Thesis_ Interview Summary (C7)

Organization: BAM Infra
Interviewees: C7
Interviewer: Ziye Huang
Location: 3981 AH Bunnik
Date: 07/02/2019

Background: C7 is an experienced maintenance supervisor in BAM. He is currently in charge of the maintenance of the A12 highway.

Part A Stakeholder Analysis

1. Knowledge
   C7: I have heard of “driverless maintenance” before your research. I know there is a mowing robot, which does not need a driver.

2. Interest
   C7: I think driverless maintenance is very good, which can improve work safety and work efficiency. If the technology is reliable, I will definitely apply it.
   C7: I did not see any disadvantages of driverless maintenance.

3. Position
   C7: I choose (b) I somewhat support driverless maintenance.

4. Alliances & Resources & Power
   C7: The reason why I somewhat support driverless maintenance is that even though I think it is a promising technology, it should be mature and reliable.
   C7: I think manufacturers should take the initiatives to develop driverless maintenance vehicles and we are very willing to cooperate with them to conduct some researches. BAM has an innovation cluster, which has financial budgets for innovation projects and will deal with the collaboration with other market parties such as manufacturers.
   C7: We are required to conduct the maintenance task in a specific period, which differs based on road sections and lanes. If we start before the period, we will receive penalty. Usually I will let my staff ask the traffic control center what the time is and based on the time there rather than ours, we will start the work.
   C7: As for whether to implement driverless maintenance, as a contractor, we should develop a business case to investigate the cost and benefit effect. Compared to the normal maintenance, driverless maintenance can improve the work safety and reduce labor costs. But it also requires a huge investment at the beginning. We wonder when can we achieve the profit point. The acceptance of the return period also depends on the contract duration. When the term of contract is longer, we are more willing to make investments.
Part B Scenarios Building

1. **Mowing**
   - C7: I don’t think working period will change.
   - C7: Working speed will also remain the same.
   - C7: The speed limit of work zones will remain the same.
   - C7: I don’t think it is necessary to make road users realize the maintenance is driverless because they will get distracted.
   - C7: I cannot see the difference of driver behaviors between non-driverless situation and driverless maintenance situation.

2. **Marker Painting**
   - C7: Working period, working speed, speed limit will also remain the same.
   - C7: The protection vehicle may not be necessary if we can add the absorber to the maintenance vehicle. But this need the approval from RWS.
   - C7: Driver behaviors will remain the same as normal.

3. **Pothole Repairs**
   - C7: Working period, working speed, speed limit will also remain the same.
   - C7: The protection vehicle may not be necessary if we can add the absorber to the maintenance vehicle. But this need the approval from RWS.
   - C7: Driver behaviors will remain the same as normal.
Master Thesis_Interview Summary (D1)

Organization: RWTH Aachen, StreetScooter, e.GO
Interviewees: D1
Interviewer: Ziyue Huang
Location: Skype Meeting
Date: 26/01/2019

Background: D1 is a PhD student in RWTH Aachen. She also works in the electric vehicle manufacturer StreetScooter and e.GO. StreetScooter works also on automated driving user cases. For instance, after DHL’s acquisition of this company, a so-called “Follow me” mode is developed for the vehicle to conduct the last mile delivery. This technology is mature now.

Part A Stakeholder Analysis

1. Knowledge
   
   D1: I haven’t heard of “driverless maintenance” before your research. But I think it is very feasible because the traffic complexity of highway is lower. In addition, the user case of driverless maintenance is more specific.

2. Interest
   
   D1: I think once driverless maintenance is implemented, the road work could be more flexible and effective. For instance, the restrictions from working period and weather would be reduced. In addition, driverless maintenance is likely to reduce the mistakes during road work. But I doubt whether the cost of driverless maintenance would be lower than manual work in some cases.

3. Position
   
   D1: I choose (c) I do not support nor oppose it.

4. Alliances & Resources & Power
   
   D1: The reason why I do not support nor oppose it is that I am not aware of its cost even though it could generate some positive impacts such as safety and efficiency improvements. So I am trying to be neutral.

   D1: As a vehicle manufacturer, we care about the market share most. If the government could guarantee some safe orders, market parties would be motivated to promote the development. In addition, driverless maintenance also need road tests, which need to require the approval from government as well. Therefore, I think the government should play the leading role.

   D1: In the development of driverless vehicles, we will cooperate with other parties, such as components supplier, IT technology supplier and universities etc. In Germany, universities need the involvement of companies to apply for engineering research projects. In turn, companies prefer to cooperate with universities to receive budgets from the government. Hence, the cooperation between research institutions and market parties are very common.
**D1:** Although I mentioned the government should be the leading role in developing driverless maintenance, a push-market is also possible. As a manufacturer, we will investigate specific user cases of driverless maintenance and develop our own business model. When we figure out it is doable, we would reach other parties for resources and persuade the government for political support.

**D1:** Vehicle manufacturers could provide technical resources on their own based on previous experience in developing automated driving technology. But they need to decide the technical route map, based on which they can purchase components from suppliers and make financial decisions. Speaking of investments, 2-3 years are acceptable as the return period for a manufacture without investors. With the support of investors, we can accept 4-5 years or even longer.

**D1:** I think the financial/technical/human resources could be quickly mobilized for us. Take StreetScooter as an example, we focus on small markets and make our products more customized.

5. **Other Supporters/Opposes**

**D1:** Road workers could oppose driverless maintenance. But I think they can find other jobs, which are safer for them.

### Part B Scenarios Building

1. **Mowing**

   **D1:** The working period will be more flexible.

   **D1:** I am not sure how the working speed would change. Maybe in the beginning, in order to guarantee the safety, the driverless maintenance vehicle will move in a lower speed.

   **D1:** I think the length of work zone will be longer so that the driverless maintenance vehicle could collect more environment data and own more time to make reactions. Or the speed limit of work zones could be reduced for the same reason.

   **D1:** I don’t think it is necessary to make road users realize the maintenance is driverless because drivers could be distracted.

   **D1:** I think driver behavior is a personal matter, which I am not sure about the change.

2. **Marker Painting**

   **D1:** I think driverless maintenance could work at the night time or in bad weather conditions to save higher salary of workers. But for other working conditions, I don’t see any difference because of closure of the lane.

   **D1:** Apart from salary saving, driverless maintenance will also generate lots of data, which could bring added value. For instance, the data can be analyzed to develop accurate maintenance, preventive maintenance and general automated driving development as well.

3. **Pothole Repairs**

   **D1:** Similarly, I think driverless maintenance could work at the night time or in bad weather conditions to save higher salary of workers. But for other working conditions, I don’t see any difference because of closure of the lane.
PS

The cost of the driverless maintenance vehicle depends on the technical route map. I think the major cost comes from components purchase and information system building.

It is cost benefit effective to integrate the driverless system into the normal vehicle rather than design a completely new one. In addition, the design of driverless maintenance vehicle should comply the laws and regulations. For instance, in a short period of time, it is difficult to remove the cabin, which, however, in the long run could be possible. Besides, the cabin does not account for a large part of the whole cost. And if the cabin is removed, the production line should also be changed, which will generate a huge extra cost, especially when the driverless maintenance market is not that large.
Master Thesis_Interview Summary (E1)

Organization: RDW
Interviewees: E1
Interviewer: Ziye Huang
Location: 2711 ER Zoetermeer
Date: 11/02/2019

Background: RDW is the vehicle authority of the Netherlands, which follows the whole life cycle of vehicles, including testing, registration etc. Every European state has its own vehicle authority and manufacturers can choose any one of them. Many manufacturers outside the Netherlands choose us because we are independent. The reason is that they don’t face competitors in the Netherlands, where there is no auto industry.

As for driverless vehicles, there is no registration in the Netherlands. It is only allowed for exemption to test these vehicles, which has drivers as back-up, on public roads. From this year, the Netherlands also allows testing of vehicles with no one on board. But this application should go to the Ministry. My task is to understand the gap between the development trend of driverless vehicles and registration.

Part A Stakeholder Analysis

1. Knowledge
   
   **E1:** I have heard of “driverless maintenance” before your research. I know there is an on-going project about the driverless protection vehicle.

2. Interest
   
   **E1:** I think driverless maintenance is very good, which can improve work safety and traffic flow. But we don’t have money for that. We just conduct the test.

3. Position
   
   **E1:** I choose (a) I strongly support driverless maintenance.

4. Alliances & Resources & Power
   
   **E1:** For every pilot test of driverless vehicles, you need to go through RDW. And if based on our assessment, the vehicle can neither enhance traffic safety, traffic flow nor environment, the application will be rejected. The assessment goes like that we examine the technical aspects and local authority judges if the vehicles could drive on its road. We will also invite SWOV and police to conduct risk analysis. Then the applicant is required to answer how would they mitigate the risks. After that all parties are gathered to discuss how to conduct the test. In the first test, we will do it on our closed test track in Lelystad. There are two types of tests, including the happy hour flow, where the surroundings are perfect and risk flow, where risks would be set on purpose. In the second test, the applicant is allowed to do the test on specific routes of specific public roads. This is a keep-learning process.
E1: The applicant will pay the test fee. The applicant can be manufacturers, municipalities etc. We don’t care who the applicant is but he is supposed to take the responsibility.
E1: We won’t take the initiatives to start the test. In the driverless maintenance case, I think maybe RWS will apply for the test. Then we will have a meeting with them.
E1: Manufacturers should be involved in the pilot test and usually we talk to them directly because we need to know how things work. If they are not part of the applicant, we will not allow the test. Manufacturers are also supposed to answer which scenarios they want to test, what risks do they have and what is their plan to mitigate the risks.
E1: I think the exemption of driverless maintenance vehicles is more difficult because there is no one board and the vehicle should be more robust. And we will ask more to mitigate the potential risk. But I think it is doable to apply such vehicles in work zones because of lower speed but it is important to make sure the vehicle works as expected.
E1: Usually manufacturers just rebuild the normal vehicle into a driverless one, which could cost 50000-100000 Euro or even more. But they will also produce a brand-new type of vehicle, which will cost millions.
E1: We have our own money from car users but we are not allowed to make profits. The pilot test fee only covers our cost.
E1: Laws and regulations are always behind, which can make market parties lack motivations. But they could invest on driverless maintenance if they see competitions. In this case, I think RWS should take the initiatives to promote the development. For instance, a business case is developed with one manufacturer and if it turns out successful, more manufacturers are willing to join.

Part B Scenarios Building

1. Mowing
   E1: Driverless maintenance vehicle can work 24 hours per day. But people may not expect this vehicle working at night, which will make them more cautious.
   E1: I have no idea how the working speed and speed limit will change.
   E1: I think it is necessary to set special signs for driverless maintenance to warn the road users because this new thing will generate risk.
   E1: I don’t think driver behaviors will change. But when this new innovation comes to the road, road users may be distracted, which leads to more accidents in the beginning. But once they get used to it, it is no problem. But it also depends on the design of the vehicle. If it looks quite different, driver behaviors might change. But if it looks like a normal truck, road users won’t notice it.

2. Marker Painting
   E1: Driverless maintenance vehicle can work 24 hours per day. But people may not expect this vehicle working at night, which will make them more cautious.
   E1: I have no idea how the working speed and speed limit will change.
   E1: I think the protection vehicle is still necessary because the painting vehicle is costly. It is less expensive when the protection vehicle is crashed.
E1: For the driver behavior, I think it is the same with the answers for mowing.

3. Pothole Repairs

E1: Driverless maintenance vehicle can work 24 hours per day. But people may not expect this vehicle working at night, which will make them more cautious.
E1: I have no idea how the working speed and speed limit will change.
E1: I think the protection vehicle is still necessary because the maintenance vehicle is costly. It is less expensive when the protection vehicle is crashed.
E1: For the driver behavior, I think it is the same with the answers for mowing.
D. Safety Culture Ladder of Rijkswaterstaat
Hoe veilig werk jij?

Ontdek het met de Veiligheidsladder

5. Vooruitstrevend
In een vooruitstrevende cultuur wordt uitgegaan van veilig en betrouwbare werken. Veiligheid is voldoende geïntegreerd in de organisatie en wordt onderdelen van bestaande processen, reflectie en evaluatie. Een goede veiligheidsprestatie wordt gezien als een indicator van goede bedrijfseffectiviteit. Management weet wat er echt aan de hand is, omdat medewerkers zich uitgebreid op deze informatie berusten. Respect voor mensen zit al in bedrijfsstructuur. Medewerkers houden altijd rekening met wat er mis kan gaan, zelfs als ze geen bijna ongevalen voorzien. Incidenten en onveilige situaties worden voorzichtig behandeld, omdat de organisatie daaraan kan leren.

4. Proactief

3. Calculatief (berekend)
In een calculatieve cultuur is er vooral veel aandacht voor systemen en procedures om risico’s te beheren. Er is een veiligheidsmanagement systeem, met voorwaarden en regels die incidenten moeten voorkomen. Er is veel nadruk op het verhogen van informatie en data, maar bij ongevallen en onveilige situaties worden ze niet altijd gedefinieerd. Omdat het op papier goed geregeld is, leidt de organisatie veilig te werken en mensen verbaasd wanneer ze zich incidenten voorstellen. Ze verwachten dat de vastgestelde regels worden toegepast. Wanneer medewerkers zich bewust bezig houden met veiligheid wordt dat door leidinggevenden gewaardeerd.

2. Reactief
In een reactieve cultuur neemt de organisatie veiligheid serieus, maar komt pas in actie als er een incident plaatsvindt. Voorgestelde verbeteringen zijn vaak achtereenvolgens, en zijn op de korte termijn. Leidinggevenden besteden weinig aandacht aan veiligheid. Ze wijzen medewerkers aan op regels en procedures, maar doen niets wanneer dat niet te zien is aan houding. Incidenten worden zeer gedeeltelijk gecontroleerd. De waardering voor veiligheid is laag. Een veel voorkomende uitspraak is: 'We doen dat op onze eigen manier en dat gaat al jaren goed.'

1. Pathologisch (ontkennend)
Een organisatie met een pathologische cultuur heeft veiligheidsproblemen. Ze is niet gevoelig voor de houding van wat de deelnemers van een ongeval, ze weigeren het aan te gaan en leiden ongevallen. Ze trekken in kaart van medewerkers, waardoor het beleid beter wordt en ze moeten niet fors geïntegreerd zijn. Ze neemt geen of weinig aandacht voor veiligheid. Het management negeert meldingen van incidenten, bijvoorbeeld terecht en deelt geen investeringen om veiligheid te verbeteren.
E. Simulation Settings
In the microscopic simulation, the road section and traffic input were selected based on a study of Aries (2015). Related parameters about driving behaviors were also set based on this study, as Figure E.1 and E.2 shows.

### Figure E.1 Following Parameters Settings

<table>
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<tr>
<th>Following</th>
<th>Car following model</th>
<th>Lane Change</th>
<th>Lateral</th>
<th>Signal Control</th>
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</table>

**Model parameters**

- CC0 (Standstill Distance): 1.50 m
- CC1 (Headway Time): 2.0 s
- CC2 (Following) Variation: 4.00 m
- CC3 (Threshold for Entering 'Following'): -8.00
- CC4 (Negative 'Following' Threshold): -0.35
- CC5 (Positive 'Following' Threshold): 0.35
- CC6 (Speed dependency of Oscillation): 11.44
- CC7 (Oscillation Acceleration): 0.25 m/s²
- CC8 (Standstill Acceleration): 3.50 m/s²
- CC9 (Acceleration with 80 km/h): 1.50 m/s²

![Figure E.1 Following Parameters Settings](image_url)
Based on the WSDOT Vissim Protocol (Washington State Department of Transportation, 2014), it is recommended in the initial test, the results of all simulation models should be reported based on a minimum of 11 simulation runs and each run must apply different random seeds beginning at one and increasing sequentially. Hence, in this study, there were 25 simulation models (speed limit: 70km/h – 110km/h; working speed: 5km/h – 9km/h) and each model was conducted for 11 runs. In order to ensure the confidence level could achieve 95%, it it necessary to calculate the number of required simulation runs based on the following formula:

\[ N = (2 \times t_{0.025,N-1} \times \frac{s}{R})^2 \]
R = Confidence interval for the true mean

$t_{0.025,N-1}$ = Student’s t-statistic for two-sided error of 2.5 percent (totals 5 percent) with N-1 degree of freedom (related to 95% confidence interval)

s = Standard deviation about the means for selected measures

N = Number of required simulation runs

The following tables summarize the results of N and 95% confidence interval for important measures:

### Table E.1 Confidence Interval of Measures (1)

<table>
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<th>Measures</th>
<th>Speed Limit</th>
<th>s</th>
<th>N</th>
<th>If pass 95% confidence level</th>
<th>Confidence Interval</th>
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<tr>
<td>Average travel time</td>
<td>70km/h</td>
<td>0.79</td>
<td>2</td>
<td>Yes</td>
<td>[167.83, 168.89]</td>
</tr>
<tr>
<td></td>
<td>80km/h</td>
<td>0.85</td>
<td>2</td>
<td>Yes</td>
<td>[163.85, 164.97]</td>
</tr>
<tr>
<td></td>
<td>90km/h</td>
<td>0.94</td>
<td>2</td>
<td>Yes</td>
<td>[162.92, 164.18]</td>
</tr>
<tr>
<td></td>
<td>100km/h</td>
<td>0.99</td>
<td>2</td>
<td>Yes</td>
<td>[162.80, 164.13]</td>
</tr>
<tr>
<td></td>
<td>110km/h</td>
<td>1.00</td>
<td>2</td>
<td>Yes</td>
<td>[162.59, 163.93]</td>
</tr>
<tr>
<td>Average delay</td>
<td>70km/h</td>
<td>0.72</td>
<td>2</td>
<td>Yes</td>
<td>[23.88, 24.84]</td>
</tr>
<tr>
<td></td>
<td>80km/h</td>
<td>0.76</td>
<td>2</td>
<td>Yes</td>
<td>[19.91, 20.93]</td>
</tr>
<tr>
<td></td>
<td>90km/h</td>
<td>0.85</td>
<td>2</td>
<td>Yes</td>
<td>[19.08, 20.22]</td>
</tr>
<tr>
<td></td>
<td>100km/h</td>
<td>0.88</td>
<td>2</td>
<td>Yes</td>
<td>[18.87, 20.05]</td>
</tr>
<tr>
<td></td>
<td>110km/h</td>
<td>0.87</td>
<td>2</td>
<td>Yes</td>
<td>[18.68, 19.84]</td>
</tr>
</tbody>
</table>

### Table E.2 Confidence Interval of Measures (2)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Working Speed</th>
<th>s</th>
<th>N</th>
<th>If pass 95% confidence level</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed</td>
<td>5km/h</td>
<td>0.40</td>
<td>1</td>
<td>Yes</td>
<td>[83.26, 83.80]</td>
</tr>
<tr>
<td></td>
<td>6km/h</td>
<td>0.47</td>
<td>1</td>
<td>Yes</td>
<td>[83.56, 84.20]</td>
</tr>
<tr>
<td></td>
<td>7km/h</td>
<td>0.46</td>
<td>1</td>
<td>Yes</td>
<td>[83.83, 84.45]</td>
</tr>
<tr>
<td></td>
<td>8km/h</td>
<td>0.46</td>
<td>1</td>
<td>Yes</td>
<td>[84.02, 84.64]</td>
</tr>
<tr>
<td></td>
<td>9km/h</td>
<td>0.45</td>
<td>1</td>
<td>Yes</td>
<td>[84.21, 84.81]</td>
</tr>
<tr>
<td>Average travel time</td>
<td>5km/h</td>
<td>0.79</td>
<td>2</td>
<td>Yes</td>
<td>[167.83, 168.89]</td>
</tr>
<tr>
<td></td>
<td>6km/h</td>
<td>0.94</td>
<td>2</td>
<td>Yes</td>
<td>[167.17, 168.43]</td>
</tr>
<tr>
<td></td>
<td>7km/h</td>
<td>0.92</td>
<td>2</td>
<td>Yes</td>
<td>[166.63, 167.87]</td>
</tr>
<tr>
<td></td>
<td>8km/h</td>
<td>0.91</td>
<td>2</td>
<td>Yes</td>
<td>[166.28, 167.50]</td>
</tr>
<tr>
<td></td>
<td>9km/h</td>
<td>0.88</td>
<td>2</td>
<td>Yes</td>
<td>[165.97, 167.15]</td>
</tr>
<tr>
<td>Average delay</td>
<td>5km/h</td>
<td>0.72</td>
<td>1</td>
<td>Yes</td>
<td>[23.88, 24.84]</td>
</tr>
<tr>
<td></td>
<td>6km/h</td>
<td>0.74</td>
<td>1</td>
<td>Yes</td>
<td>[23.30, 24.30]</td>
</tr>
<tr>
<td></td>
<td>7km/h</td>
<td>0.79</td>
<td>2</td>
<td>Yes</td>
<td>[22.72, 23.78]</td>
</tr>
<tr>
<td></td>
<td>8km/h</td>
<td>0.81</td>
<td>2</td>
<td>Yes</td>
<td>[22.35, 23.43]</td>
</tr>
<tr>
<td></td>
<td>9km/h</td>
<td>0.70</td>
<td>1</td>
<td>Yes</td>
<td>[22.09, 23.03]</td>
</tr>
</tbody>
</table>

It is concluded that 11 runs of simulation could achieve 95% confidence level for all measures. And based on the significance test, when the speed limit increased, all measures demonstrated significant difference from those in the basic scenario (speed limit = 70km/h; working speed = 5km/h) under 95% confidence level. But when the working speed increased, only when it reached 7km/h or higher speed, all measures could present significant difference from those in the basic scenario. As for traffic safety measures, in Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12, Figure 5.14, Figure 5.15, Figure 5.16 and Figure 5.17,
the rest curves were not significantly different from the curve of speed limit = 70km/h and that of working speed = 5km/h (basic scenario) under 95% confidence level. This result was achieved based on the K-S test in Matlab. The null hypothesis that other curves were from the same distribution from that of the basic scenario was accepted by the result of 0. The p-values was summarized in the following table:

Table E.3 P-values of Measures (1)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Speed Limit</th>
<th>p-value</th>
<th>If accept the null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headway (s)</td>
<td>80km/h</td>
<td>0.7942</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>90km/h</td>
<td>0.8938</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>100km/h</td>
<td>0.8938</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>110km/h</td>
<td>0.8938</td>
<td>Yes</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>80km/h</td>
<td>0.9995</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>90km/h</td>
<td>0.9995</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>100km/h</td>
<td>0.9995</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>110km/h</td>
<td>0.9995</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table E.4 P-values of Measures (2)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Working Speed</th>
<th>p-value</th>
<th>If accept the null hypothesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headway (s)</td>
<td>6km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>7km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>8km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>9km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td>Speed (km/h)</td>
<td>6km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>7km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>8km/h</td>
<td>1.0000</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>9km/h</td>
<td>0.9995</td>
<td>Yes</td>
</tr>
</tbody>
</table>
F. Cost-Benefit Table
Table F.1 Cost Benefit Analysis of Driverless Mowing

<table>
<thead>
<tr>
<th>Benefits (euro)</th>
<th>2020</th>
<th>……</th>
<th>2030</th>
<th>……</th>
<th>2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1 light injury)</td>
<td>22,000</td>
<td>22,000</td>
<td>22,000</td>
<td>22,000</td>
<td>22,000</td>
</tr>
<tr>
<td>(1 severe injury)</td>
<td>290,000</td>
<td>290,000</td>
<td>290,000</td>
<td>290,000</td>
<td>290,000</td>
</tr>
<tr>
<td>(1 death)</td>
<td>2,600,000</td>
<td>2,600,000</td>
<td>2,600,000</td>
<td>2,600,000</td>
<td>2,600,000</td>
</tr>
</tbody>
</table>

(1) Reduction of Death and Injuries

| (1 light injury) | 8,600 | 8,600 | 8,600 | 8,600 | 8,600 |
| (1 severe injury) | 281,000 | 281,000 | 281,000 | 281,000 | 281,000 |
| (1 death) | 2,612,000 | 2,612,000 | 2,612,000 | 2,612,000 | 2,612,000 |

(2) Reduction of Labor Costs

| 9,600 | 9,600 | 9,600 | 9,600 | 9,600 |

(3) Reduction of Travel Time

| 36,000 | 36,000 | 36,000 | 36,000 | 36,000 |

(4) Reduction of Safety Measures

| + | + | + | + | + |

(5) Extra Job Opportunities

| + | + | + | + | + |

(6) Creating New Database

| + | + | + | + | + |

Costs (euro)

| 230,000 | 4,000 | 230,000 | 4,000 | 4,000 |

(1) Technical Investment

| 225,000 | 225,000 |

(2) Increased Emissions

| 330 | 330 | 330 | 330 | 330 |

(3) Increased Fuel Consumption

| 3,500 | 3,500 | 3,500 | 3,500 | 3,500 |

(4) Maintenance Costs of Vehicles and Systems

| - | - | - | - | - |

(5) Short-term Job Loss

| - | - | - | - | - |

(6) Pilot Test Costs

| - | - | - | - | - |

Net Value (euro)

| -208,000 | 18,000 | -210,000 | 18,000 | 18,000 |
| 60,000 | 286,000 | 60,000 | 286,000 | 286,000 |
| 2,370,000 | 2,370,000 | 2,600,000 | 2,600,000 | 2,600,000 |

Net Present Value

| -120,000 | 4,200,000 | 41,000,000 | 179 |
The calculation of benefits (1)(2)(3) and costs (1)(2)(3) were explained as follows:

**Benefits**

(1) **Reduction of Injuries and Death**: as mentioned in Section 5.1, mowing is already very safe and this parameter was selected to conduct sensitivity analysis. In this case, an annual reduction of 1 light injury, 1 severe injury and 1 death were compared. Based on Rijkswaterstaat (2009), the cost of 1 light injury is 8600 euro (Rijkswaterstaat, 2009). The cost of 1 severe injury is 281000 euro and the cost of 1 death is 2612000 euro.

(2) **Reduction of Labor Costs**: in order to calculate this cost, it is necessary to make some assumptions. Based on interviewee C6, mowing has to be done twice every year. Supposing each period of mowing lasts one month and driverless mowing vehicle works 8 hours per day and 20 days per month. As recommended in Section 5.4, the speed limit was set as 90 km/h and the working speed as 7km/h. Then the mowing vehicle could mow 1120 km per month and 2240 km per year. The saved labor costs per year equals to 30 euro/h*320 h/year, namely 9600 euro.

(3) **Reduction of Travel Time**: as mentioned before, the average travel time decreases by around 5s when road work lasts 30 minutes. Then the saved time per year equals to 320*2 h/year*5s, namely 3200s and 0.9 h for each vehicle, according to the simulation. In the simulation, 70% of the road users are passengers and 30% of the traffic flow is flight transportation. Based on Rijkswaterstaat (2017), the value of time for freight transportation is 47.32 euro per hour and that for passengers is (9.69+29.85+7.86)/3 = 15.8 euro per hour. Hence, the annual reduction of travel time is 47.32 euro/h*30%*0.9h+15.8 euro/h*70%*0.9h = 20 euro for each vehicle. Considering the traffic volume in the simulation, the total saved time per year equals to 20*1800 vehicle=36000 euro.

**Costs**

(1) **Technical Investment**: the technical investment was estimated to be 225000 euro, as Section 7.2 explained. It is assumed that the life cycle of the mowing vehicle is 10 years. Hence, in 2030 there should be another technical investment at the price of 225000 euro, supposing the amount of investment remains the same.

(2) **Increased Emissions**: The emissions increased by 92.5 grams in 30 minutes of road work. Therefore, the annual increased emissions were 320*2 h/year*92.5 = 59200 grams, namely around 60 kilograms. According to simulation, the composition of emissions includes 70% COx, 15% NOx and 15% VOC (Volatile organic compound). Based on Rijkswaterstaat (2010), the annual cost of increased emissions was evaluated to be 60kg*(70%*0.057 euro+15%*34.7 euro+15%*2.1 euro) = 330 euro.

(3) **Increased Fuel Consumption**: the fuel consumption increased by 1 gallon for 30 minutes of road work in driverless mowing situation. Hence, the annual increased fuel consumption was calculated as 1*3.78 (liter/gallon)*320*2 h/year = 2419 liters. Based
on Autotraveler (2019), the fuel price in the Netherlands is 1.45 euro per liter. Hence, the annual cost of increased fuel consumption was evaluated to be 3500 euro.