Introducing ADAS Evaluation into a Driving Exam: An Examiner's Perspective

Arav Kharkwal

Introducing ADAS Evaluation into a Driving Exam: An Examiner's Perspective

Author

Arav Kharkwal

Master of Science in Civil Engineering – Transport and Planning

September 2023

Graduation Committee

Chairperson, TU Delft	Prof. Dr. Marjan Hagenzieker
Examiner, TU Delft	Dr. Ir. Simeon Calvert
Supervisor, TU Delft	Dr. Sina Nordhoff
Supervisor, CBR	Dr. Daniël Heikoop

Preface

I am pleased to present this thesis, which stands not just as the culmination of my MSc research, but also as an emblem of my personal and professional growth over the past two years. The journey towards achieving this degree was challenging, yet immensely rewarding, teaching me resilience, dedication, and the importance of perpetual learning.

I am very grateful to my advisors: Prof. Dr. Marjan Hagenzieker, Dr. Ir. Simeon Calvert, Dr. Sina Nordhoff, and Dr. Daniël Heikoop. Each of them has inspired me to evolve as a researcher, providing invaluable guidance and encouragement throughout. I also wish to acknowledge *CBR* for their invaluable contribution to my research. Their willingness to facilitate interviews and schedule case studies with driving examiners was pivotal, as these individuals were the main participants of this research.

At the heart of all my efforts are my family - my parents, Amitabh and Lavina, and my dear sibling, Arushi. Their unwavering love and support have been my anchor.

This thesis represents my original contribution to the field of Civil Engineering. I hope this work provides new insights and opens up avenues for future exploration. I see this as the beginning of a lifelong pursuit of knowledge.

Cover Image: Great Rex, L. (2021). Driving test [Image]. gov.uk. https://despatch.blog.gov.uk/2021/10/06/adi-standards-checks-your-data-and-parameter-questions-answered/

Abstract

This research developed a novel assessment method to enable driving examiners to effectively evaluate the safe use of Advanced Driver Assistance Systems (ADAS) during practical driving exams in the Netherlands. An Assessment Matrix was developed and refined through expert interviews, observations, and case studies.

The need to streamline licensing protocols, focus on safety critical competencies and expand examiner training were highlighted in the interviews. ADAS functionality across scenarios and constraints within the driving exam was observed in the case studies.

Safety critical competencies identified through observations were monitoring systems, smooth manual takeover, and avoiding distraction. The refined ADAS matrix enabled standardized evaluation despite operational constraints. The findings emphasized integrating ADAS assessments into existing exams, hands-on examiner training, and public education to address knowledge gaps.

Recommendations included streamlining assessments, evaluating overall competence, aligning training, providing immersive examiner education, and collaborations to match training with vehicle automation advances. Limitations included sample size and generalizations.

For the first time, an empirically validated ADAS evaluation matrix was developed to promote integrating safety critical ADAS competency within the constraints of the practical driving exam. Further research could build on this to refine protocols and ensure that drivers acquired the needed skills as vehicle automation advances.

Executive Summary

This research aims to enhance road safety by developing an assessment method for driving examiners to evaluate the safe use of Advanced Driver Assistance Systems (ADAS) during practical driving exams in the Netherlands.

Current driver training and testing lacks comprehensive evaluation of ADAS competency, despite its increased integration in vehicles. This gap motivated the licensing organization in the Netherlands to include ADAS guidelines in practical exam criteria for the first time. However, a standardized assessment method is still needed.

This research also identifies evaluation gaps and validates a novel ADAS assessment matrix, through literature review, field observations, examiner interview and establishes an assessment criteria. Recommendations are provided on incorporating ADAS checks into driving exams.

Though the context is Dutch, this methodology can be a useful assessment tool in other regions as well. Its limitations are generalizations, subjectivity and challenges in feasible implementation, due to rapidly evolving technologies. Overall, the research aims to equip examiners with an evidence-based, validated assessment method to evaluate safe ADAS use during driving exams.

Literature Review

The literature review provides an overview of research on ADAS and their potential role in practical driving exams. The review reveals several gaps in evaluating safe ADAS use. Currently, ADAS competency is not systematically assessed, though some countries like the

Netherlands are taking initial steps (CBR, 2023b; Vlakveld & Wesseling, 2018). There is very limited research examining ADAS evaluation methods. Studies also show examiners have insufficient ADAS familiarity (Heikoop et al., 2020). These gaps highlight the need for formal procedures.

Safety critical ADAS-related behaviors for evaluation include system activation/deactivation, monitoring, trust calibration, timely manual takeover, and handling limitations (Banks & Stanton, 2019; Spulber, 2016). Examiners must confirm ADAS knowledge on purposes, automation levels, control transitions, and limitations (Casner & Hutchins, 2019; Manser et al., 2019).

Recommendations include integrating ADAS assessments into driving exams through a framework evaluating knowledge, skill, and behavior dimensions (van den Beukel et al., 2021). Extensive ADAS training is needed for examiners to understand system capabilities, limitations, and safe interaction assessment. Graduated licensing programs should also expand ADAS components along with developing technologies (Polders et al., 2017). In summary, the literature review highlights that systemic ADAS evaluation in driving exams is needed but is challenging to implement.

Methodology

The research employs a qualitative approach to develop and validate an ADAS Assessment Matrix. Methods included an initial case study observing mock driving exams, interviews with examiners to refine the matrix, and a second case study testing the efficacy matrix in a real-world setting.

The iterative process enables direct insights into real-world ADAS usage and assessment challenges from practitioner perspectives. Ethical approvals were obtained, with protocols followed to protect participant privacy and confidentiality. The methodology facilitated an in-depth, multi-faceted investigation grounded in practitioner experiences to effectively develop and validate an ADAS assessment tool for driving examiners.

Results & Discussions

The chapter on results presents the development and refinement of the ADAS Assessment Matrix through case studies and examiner interviews. Key findings include the conditional operation of ADAS across scenarios, complexity of concurrent ADAS activation/deactivation, and the need for integration with existing testing protocols.

The discussion chapter interprets these results, noting the importance of adaptable evaluations, emphasizing holistic competencies, and incorporating essential ADAS knowledge and skills, within time limitations. Examiner perspectives highlight the needs for ADAS education, hands-on practice, and regular training updates.

While the matrix provides an initial tool for evaluating safe ADAS use, further research could enhance assessment standardization, validity, and reliability. Overall, the study underscores gradually integrating ADAS evaluations within current testing constraints, through an evidence-based approach.

Conclusions

The conclusions chapter answers the research questions and addresses gaps in evaluating safe ADAS use by summarizing the development of the ADAS Assessment Matrix during driving exams. Key gaps identified include outdated assessment priorities, lack of standardized licensing protocols, examiner readiness limitations, and practical feasibility constraints.

Core competencies for evaluation are proposed, like maintaining awareness of the surroundings, and smoothly regaining manual control. Recommendations include integrating ADAS checks into existing tools, focusing holistically on key skills, streamlining protocols, expanding examiner training, and sustained collaborative efforts between stakeholders, to continuously improve assessments.

Overall, an empirically validated ADAS evaluation matrix was developed to promote integrating safety critical ADAS competency within the constraints of the practical driving exam. Further research could build on this to refine protocols and ensure that drivers acquired the needed skills as vehicle automation advances.

Table of Contents

Chapter 1 – Introduction

Advanced Driver Assistance Systems (ADAS) refer to a set of technologies that assist drivers in performing a range of driving tasks. An integral component of modern automotive technology, there is evidence that these systems improve traffic safety (Ye & Yamamoto, 2019), increase road capacity (Shi et al., 2019), and reduce emissions (Yao et al., 2021). Recognizing their potential for improving safety, the European Union took steps to ensure the prevalence of certain ADAS in cars. Effective July 6, 2022, European Union Regulation 2019/2144 mandated the installation of six ADAS technologies in new car models (EU, 2019). These mandated technologies, such as driver distraction warnings, speed limiting, and automatic emergency braking, represent a commitment to improve traffic safety in Europe.

Despite the progressive integration of ADAS into vehicles in Europe, evaluating the safe use of these systems by drivers within driver training and examinations has remained limited. This highlights a potential gap in ensuring the safe use of these systems. With the Netherlands employing a test-driven approach to driver training, where the driving examination dictates the content of prior driver training, this gap could result in drivers not being properly trained on how to use ADAS technologies safely. This is underscored by the unanimous sentiment of Dutch driving examiners who acknowledge that ADAS evaluation lacks comprehensive and structured incorporation in both driver training and testing (Heikoop et al., 2020; Tsapi, 2020)

A turning point emerged in January 2023, when *Centraal Bureau Rijvaardigheidsbewijzen (CBR),* the organization responsible for administering theoretical and practical driving tests in the Netherlands, released an update to the *Rijprocedure B* document. The document, which details the expected skills, behaviors, and procedures a candidate should demonstrate during a category B (car) driving test, was updated to introduce guidelines for the safe use of ADAS. This highlights the importance of integrating ADAS evaluation into the driver licensing process. Building on this momentum and recognizing the need

for a standardized evaluation method, this research seeks to develop an assessment method that enables Dutch examiners to effectively evaluate a driver's use of ADAS during the practical driving exam. In addition, the developed method will also be validated by Dutch driving examiners. Ultimately, evidence-based recommendations on incorporating ADAS evaluation into current driver licensing protocols will be provided. This introduction will further detail the problem statement, followed by the research objective and ensuing research questions. It will then outline the scope of this research, discuss its scientific relevance to the field of driver training and testing, and acknowledge key limitations that bound the study.

1.1 Problem Statement

In light of the European Union's directives and the increasing integration of ADAS into modern vehicles, a significant discrepancy has emerged in evaluating the use of these systems within driver training and examinations in the Netherlands (EU, 2023)The prevailing driver training paradigm, predominantly test-driven, does not effectively encompass the intricacies of ADAS usage. This concern is reinforced by Dutch driving examiners (Vlakveld & Wesseling, 2018). The recent update to the *Rijprocedure B* document by CBR (2023b) underscores the need for a more comprehensive ADAS assessment. It emphasizes an evaluation method that evaluates a driver's safe use of ADAS and receives the endorsement of driving examiners. Addressing this need is pivotal to standardizing ADAS evaluations, ensuring drivers harness the full benefits offered by ADAS, and fostering a generation skilled in using new-age driving technologies.

Therefore, there is a clear call for an evidence-based ADAS assessment method and strategic recommendations for its seamless integration into driving tests.

1.2 Research Objectives

The objective of this research is to **enhance road safety by equipping driving examiners with a method to evaluate the safe use of Advanced Driver Assistance Systems.**

The sub-objectives are to:

1. Review research and current practices in driver assessment to identify gaps in evaluating the safe use of ADAS.
2. Develop an assessment method for driving examiners that addresses the gaps identified in the first sub-objective.
3. Validate the developed driver assessment method by obtaining structured feedback from driving examiners through field experiments and interviews.
4. Provide recommendations on incorporating ADAS evaluation into current driver licensing protocols and address barriers to its implementation.

1.3 Research Questions

The main research question is, **"How can driving examiners effectively evaluate safe use of Advanced Driver Assistance Systems by a candidate during a practical driving exam?**".

The following sub-questions will together help address the main research question:

1. What are the current gaps in evaluating safe ADAS use during a driving exam?
2. Which ADAS-related driver behaviors are essential for driving examiners to evaluate for safe ADAS use?
3. How can observing ADAS use in real-world driving situations inform effective evaluation methods for examiners?
4. What recommendations can be made based on the findings to effectively incorporate ADAS use evaluation into the driving exam?

1.4 Research Scope

This research aims to develop a framework for assessing safe use of ADAS by drivers during practical driving exams in the Netherlands. It will focus on the nation's driver testing regulations and procedures. The goal is to design an assessment tool, specifically for Dutch driving examiners, evaluate safety critical ADAS skills within existing exams. Feedback will be gathered from a group of experienced examiners, with observations limited to mock exams due to ethical considerations. Only ADAS systems directly related to operational vehicle control will be considered. While the developed tools are specific to the Netherlands, the methods used to create this framework can be adapted for other licensing organizations.

1.5 Scientific Relevance

Developing an evidence-based assessment framework for evaluating safe use of ADAS during a practical driving exam has the potential to improve road safety. Currently, examiners lack validated tools tailored for this purpose. This research will establish assessment criteria grounded in both scientific literature and real-world observational data. The findings can inform the design of assessment tools for evaluating safe use of ADAS. Additionally, the study will provide data-driven recommendations to shape ADAS training and testing best practices. Standardized evaluation methods for safe ADAS usage are crucial, especially as licensing organizations look to integrate it into current and future driving technologies. The implications of this research are in the field of driver assessment and training, with the overarching goal of enhancing road safety. However, it is also crucial to recognize the study's limitations.

1.6 Limitations

This study primarily focuses on driver assessment within the Netherlands, so the developed method's applicability may be limited elsewhere. Being qualitative in nature, the research carries inherent subjectivity during both the data collection and analysis phases; however, measures will be put in place to curb potential biases. It is essential to note that as ADAS technologies are evolving, the approach outlined needs to be flexible to accommodate future changes. The presence of specific ADAS in exam vehicles can also pose constraints. For ethical reasons, directly observing novice drivers aiming for licensure isn't feasible. Moreover, observations of real-world driving can bring about variability and subjectivity in the captured data. Lastly, recommendations deviating significantly from current exam procedures may be challenging to implement.

1.7 Organization of Document

Having outlined the research's scope and limitations, this document presents the entire research process as organized in the following chapters. Chapter 2 provides a review of relevant literature. Chapter 3 outlines the methodology, including development of the ADAS Assessment Matrix. Chapter 4 presents the developed matrix and results of the case studies and interviews used to iterate and validate the matrix. In Chapter 5, these results are discussed along with the limitations. Finally, Chapter 6 summarizes the report's conclusions by answering the research questions.

Chapter 2 – Literature Review

Section 1 – Introduction

This section introduces the key concepts and objectives underpinning the literature review. It begins by defining ADAS and outlining their significance in improving road safety. The section then establishes the aims, methodology, and structure of the literature review to provide a framework for the in-depth analysis that follows.

Section 1.1 ADAS and Significance

"Advanced Driver Assistance Systems" (ADAS) refer to a variety of vehicle technologies that aim to assist the human driver in performing the driving task. Improving traffic safety (Ye & Yamamoto, 2019), increasing road capacity (Shi et al., 2019), and reducing emissions (Yao et al., 2021) are few of the potential benefits brought by ADAS. By reducing the risk of accidents, ADAS represents one of the major advancements in the automobile industry in terms of road safety (Cicchino, 2017). Additionally, ADAS can also alleviate driver fatigue and stress by automating certain driving functions. However, these advancements bring with them their own challenges to the various stakeholders. To utilize the full benefits of ADAS, researchers and policymakers unanimously call for updating training and testing practices to account for developments in technology (Polders et al., 2017; Roemer, 2021; van Driel et al., 2019). This research aims to provide recommendations on how ADAS can be evaluated during the practical driving exam. To do this, a literature review was conducted per the research tasks identified.

Section 1.2 Objective of literature review

This literature review aims to provide an in-depth understanding of the interaction between the current state of ADAS technology, its use by drivers, and its potential role in the practical driving exam. Simultaneously, it seeks to review driver assessment methods in the Netherlands to answer the research question “How can driver interaction with Advanced Driver Assistance Systems be effectively evaluated

during the practical driving exam?”. The insights from this review will help answer the research questions using a methodology backed by literature and by means of an evidence-based approach.

Section 1.3 Method of literature review

This section defines the systemic approach undertaken to collect and analyze literature pertinent to the research question. It details the steps involved in the selection criteria, search, software and databases used for the search, and other relevant information.

The review process commenced with the identification of pertinent keywords. A dual-faceted approach guided this process. Initially, keywords directly connected to the central theme of the research question were selected. These comprised specific terms encompassing ADAS, driver assessment, and licensing: "*advanced driver assistance systems*", "*driver assistance systems*", "*driver assessment*", and "*driver licensing*". "*Safety*" was included as an additional keyword, given that one of the prime objectives in the evolution of ADAS is the enhancement of road safety. A secondary set of keywords was subsequently identified to provide contextual depth and enhanced understanding of the themes inherent in the research question. This set incorporated terms such as “*driver education*", "*driver training*", "*driver testing*", "*driving examiner*", "*examiner*", "*automated driving systems*", "*automated vehicles*", and "*human factors*".

A comprehensive search strategy was implemented to identify peer-reviewed literature that aligned with the selected keywords and was relevant to the research question. To implement this search strategy, two databases were utilized: Google Scholar and Scopus. In addition to Google Scholar, the Scopus database was searched to provide wider coverage of peer-reviewed literature. While Google Scholar is publicly accessible, access to Scopus was facilitated due to the researcher's affiliation as a graduate student with the Technical University of Delft (TU Delft). To search for literature, a strategy that identified peer-reviewed sources per the selected keywords and relevance to the research question was applied. Two databases were used to search for relevant literature, Google Scholar and Scopus. Google

scholar is freely accessible to the public, whereas access to Scopus was made possible by means of being a student at TU Delft, an institute that allows its students and faculty to access the database. Harzing's Publish or Perish software version 8 was used to streamline the literature search process within the aforementioned databases. Here, the combined keywords were inputted and sources from the year 2012 and onwards were identified to ensure the captured literature is contemporaneous and reflective of the current state of the field. Screening and filtering of the sources were then conducted based on relevance and alignment with research objectives. Initially, titles and abstracts were scanned for immediate relevancy. The key inclusion criteria at this stage were a clear focus on ADAS, driver assessment, and licensing, or closely related topics. Studies that did not meet these criteria were excluded. Consequently, full-text articles of the remaining studies were obtained and thoroughly assessed. Studies that did not contribute substantial knowledge to the research question were excluded.

An ancestry search approach, or snowball sampling, was also utilized to identify relevant documents from years prior to 2012 (Atkinson et al., 2015). This approach led to the inclusion of grey literature, such as organizational reports, conference proceedings, position papers, and government documents (Schopfel, 2010). These were critically evaluated based on their relevance and the credibility of their sources. Given the importance of automakers and governments, organizational reports, conference papers, position papers, and government documents were critically analyzed. A thorough web-based search was employed, employing identical keywords to uncover any essential information related to the research objectives previously unsourced. The selection of English-language sources for peer-reviewed literature was a deliberate choice, influenced by the global academic community's inclination towards English as the primary language for significant scholarly discourse. Nonetheless, the limitations of this linguistic preference should not be understated. This approach may inadvertently exclude relevant research published in other languages, potentially leading to linguistic bias and a narrower cultural perspective. However, given the practical constraints of time, resources, and

translation proficiency, an exhaustive multi-lingual review was not possible in this instance. Grey literature and web search results, however, diverged from this English-only stipulation, also encompassing Dutch language sources. This decision stemmed from the observation during the preliminary review that Dutch grey literature was significantly richer in content pertinent to this study than comparable documents in other non-English languages. Incorporating Dutch sources hence allowed for a more nuanced, localized understanding of the topic without disproportionately increasing the scope and complexity of the review process. To briefly summarize, the search process involved three stages: 1) keyword searches in Google Scholar and Scopus databases, 2) ancestry approach to identify older relevant sources, and 3) targeted gray literature search.

Section 1.4 Overview of sections

In the literature review, each segment addresses a different aspect of the ADAS and its role in practical driving examinations. In Section 2, titled "Evolution of ADAS," the focus is on the development and progression of ADAS. This part highlights their critical function in improving road safety. It scrutinizes a range of ADAS technologies currently available in the market, discusses their functionalities, and elucidates the technological principles they are built upon. Additionally, the limitations of these systems are also addressed, offering valuable insights into areas requiring improvement and further advancement. Section 3, "Driver Assessment in the Netherlands," explores the extant procedures for obtaining a driving license in the Netherlands, paying particular attention to the protocols preceding assessment. It entails an evaluation of the current driver training methodologies and examines the role of the examiner during the training and testing stages. The aim of this section is to present a comprehensive understanding of the existing assessment practices and pinpoint potential areas for the integration of ADAS. This provides the necessary background on existing assessment practices before analyzing how ADAS may be integrated. In Section 4, "Interaction of Drivers with ADAS," the review investigates the nature of interactions between drivers and ADAS. It delves into how these novel

technologies modify driving experiences. This part employs relevant models to comprehend these interactions and outlines the ensuing requirements for safely operating vehicles equipped with ADAS. Section 5, "Driver Education and Training with ADAS," examines the methods employed to educate and train drivers about ADAS. It assesses various learning models and training programs that equip drivers with the necessary skills and knowledge to operate ADAS-enabled vehicles effectively and safely. The analysis in this section is intended to contribute to the development of efficacious strategies for incorporating ADAS into driver education. In Section 6, titled "Role of ADAS in Practical Driving Exams," the review explores potential ways to integrate ADAS into practical driving exams. It discusses the possible impacts this integration may have on test design and execution, and it provides an understanding of how ADAS may reshape the future landscape of driver assessment. In summary, this literature review will provide a comprehensive overview of ADAS and driver assessment.

Section 2 – Advanced Driver Assistance Systems

The objective of Section 2 is to elaborate on the foundational knowledge established in Section 1 by delving into the technological details of ADAS. This section illuminates the current state of ADAS in vehicles, thus building on the initial introduction and significance of these systems provided in the preceding section. Comprehending the history, diversity, functionality, and operational limitations of ADAS technologies enables a more robust and informed analysis of their role in practical driving exams. Furthermore, this in-depth exploration contributes to the broader research objective by setting the technical context for forthcoming discussions about driver-ADAS interactions, assessment methods, and training.

Section 2.1 Introduction

This section scrutinizes the current state of ADAS technology. By investigating the features and operational limits of ADAS-equipped vehicles, a comprehensive understanding of contemporary developments in this field is fostered. Given the spectrum of systems and the level of support they offer

to drivers, it is critical to employ an appropriate framework to classify the varying degrees of technology in vehicles. Automation is defined as 'a technology concerned with performing a process by means of programmed commands. Combined with automatic feedback control to ensure proper execution of the instructions (Groover, 2023). Standards by SAE (2021), (NHTSA, 2022), and VDA (Luetge, 2017) use different levels that correspond to the different distribution of tasks between the driver and the automated systems and are all applicable to the context of this research. However, due to SAE J3016 providing more clarity around levels of automation and control, along with influencing discussions among researchers and policymakers more than the other standards, it will be employed as a reference throughout this research (Edwards et al., 2020).

The SAE (Society of Automotive Engineers) approach describes six levels of automation, ranging from no automation (Level 0) to full automation (Level 5) (SAE, 2021). At Level 0 (no automation), the individual driving is under full control of the vehicle. The vehicle may issue warning or alert, but the driving task is performed entirely by the driver. At Level 2 (partial automation), the vehicle can control both speed and steering under certain conditions, with the driver required to continuously monitor the environment and retake control when required. At Level 3 (conditional automation), the vehicle can handle all aspects of the driving task under certain conditions, with the driver required to retake control when requested by the vehicle. At this level, the driver is not required to continuously monitor the environment. At Level 4 (high automation), the vehicle can handle all aspects of the driving task under certain conditions and reach a safe state without intervention from the driver. At Level 5 (full automation), the vehicle is capable of performing all driving tasks and under all conditions that an experienced driver could manage. In 2021, the SAE refined the SAE J3016 standard with more clear and concise terminology (SAE, 2021), illustrated in Figure 1.

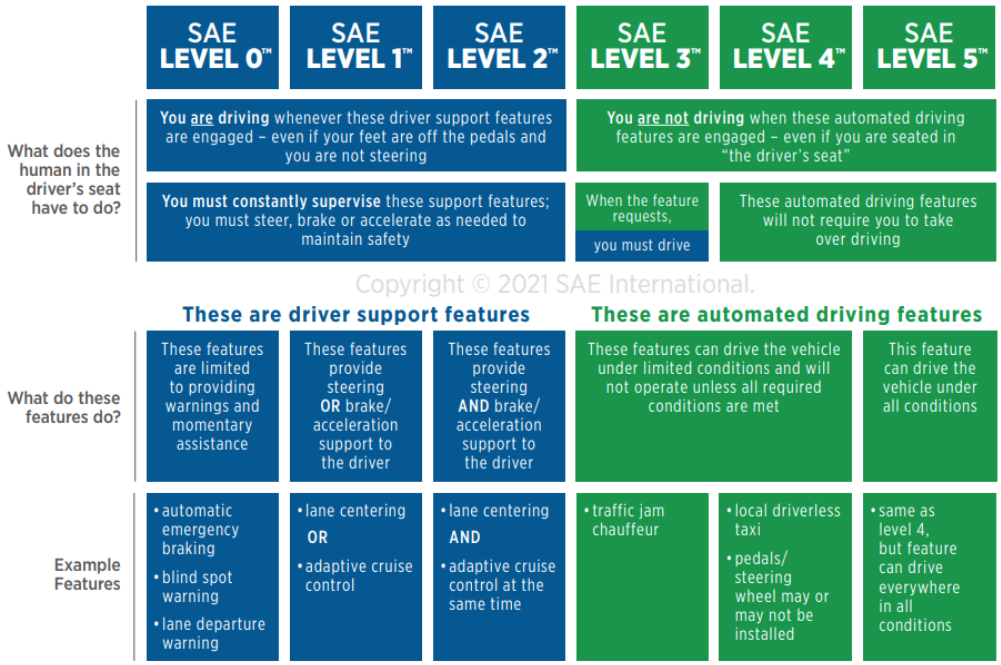

Figure 1-SAE Level of Driving Automation (SAE, 2021)

Section 2.2 What is ADAS?

The term "Advanced Driver Assistance Systems" (ADAS) refers to a wide variety of vehicle technologies that aim to assist human drivers in performing the driving task. This can be in the form of a warning, partially taking over the driving task from the human driver, and/or intervening in critical situations by completely taking over the driving task. The warning typically consists of a combination of various visual, auditory, and haptic feedback cues. In addition to improving road safety, some ADAS are also focused on improving driver comfort by partially taking over the driving task under certain conditions.

2.2.1 Evolution of ADAS Technologies.

The evolution of ADAS can be traced back to the mid-20th century when basic analog systems were introduced to enhance driving safety (Galvani, 2019). Early precursor systems, such as Anti-lock Braking Systems (ABS) and Electronic Stability Control (ESC), laid the groundwork for the development of modern ADAS. ABS, developed in the 1950s, improved vehicle control during abrupt braking, while the

later-introduced ESC in the 1980s provided stability in adverse driving conditions by autonomously applying brakes to individual wheels (Gowda & Ramachandra, 2018).

The late 20th and early 21st centuries saw a leap in ADAS development due to advancements in digital technologies, including machine learning and artificial intelligence. This period gave birth to a new generation of ADAS, such as Adaptive Cruise Control (ACC), Lane Departure Warning Systems (LDWS), and Autonomous Emergency Braking (AEB). These systems not only provided reactive assistance but also incorporated proactive elements, intervening even before the driver was aware of the impending danger (Maurer, 2016)

2.2.2 Sensing Technologies Enabling ADAS.

ADAS relies on various sensing technologies to perceive the driving environment. Cameras capture visual information and excel at image recognition but can struggle in poor visibility conditions (Zhong et al., 2018). Radar uses radio waves to detect objects and measure distance and speed, performing reliably in bad weather but lacking ability to classify objects (Enayati et al., 2022). Lidar employs pulsed lasers to generate precise 3D maps of surroundings, albeit at a higher cost and with some weather limitations (Goodin et al., 2019). Ultrasonic sensors detect nearby obstacles and are valued for park assist systems despite limited range (Xu et al., 2023). The strengths and weaknesses of these technologies are often complementary, so combining them provides comprehensive environmental sensing for ADAS to understand driving scenarios. Rather than any single technology, fusion of camera, radar, lidar, and ultrasonic information enables ADAS to achieve reliable, all-weather operation (Ziebinski et al., 2017). Careful sensor selection and integration tailors the sensing suited to the particular ADAS application requirements.

Section 2.3 ADAS, Functions, and Operational Limits

In modern vehicular technology, comprehending the function, effect on road safety, and limitations of Advanced Driver Assistance Systems (ADAS) is vital. Table 1 gives an overview of prevalent

ADAS, summarizing their primary capabilities, their measurable impacts on road safety grounded in considerable research studies, and their limitations. Though some ADAS features have proven to notably improve road safety, others necessitate further empirical validation. Improving vehicular driving habits appears to be a leading approach to attaining the highest level of safety (Tsapi, 2015). Thus, reviewing these systems and their limitations is essential.

Table 1-ADAS Type, Description, Effect on Road Safety and Limitations

ADAS Type	Description	Effect on Road Safety	Limitations
Forward Collision Warning (FCW)	Alerts driver of imminent collision with slower/stopped vehicle ahead	Reduces front-to-rear crashes by 27% and injury crashes by 20% (Cicchino, 2017)	Adverse weather, narrow/winding roads, stopped/slow vehicles ahead, pedestrians around vehicle
Automatic Emergency Braking (AEB)	Applies brakes to avoid or mitigate crash if driver does not respond to FCW	Reduces rear-end crashes by 50% when combined with FCW (Cicchino, 2017)	Same as FCW
Lane Departure Warning (LDW)	Alerts driver drifting out of lane	Reduces injury crashes by 24% (Cicchino, 2018b)	Adverse weather, unclear lane markings, narrow/winding roads, sensor issues
Lane Keeping Assist (LKA)	Steers vehicle to center of lane	No conclusive studies found	Same as LDW
Blind Spot Warning (BSW)	Alerts driver to vehicles in blind spot	Reduces lane-change crashes by 14% (Cicchino, 2018a)	Same as LDW
Pedestrian/Cycle/Object Detection	Detects vulnerable road users/objects in path	No conclusive studies found	Poor visibility, bright lights, road debris, obstructions, narrow roads, damaged panels, extreme temperatures
Adaptive Cruise Control (ACC)	Maintains speed and distance to vehicle ahead	No clear effect found (Vlakveld, 2019)	FCW + LDW Limitations
Intelligent Speed Assist (ISA)	Displays speed limit and can limit speed	Effective at reducing speed on 60 km/h roads (De Vos et al., 2023)	Poor visibility, bright lights, road debris, obstructions, narrow roads, damaged panels, extreme temperatures

ADAS Type	Description	Effect on Road Safety	Limitations
Autopilot (Tesla)	Traffic-aware cruise control + auto steering + auto lane change	No conclusive studies found	Poor visibility, bright lights, road debris, obstructions, narrow roads, damaged panels, extreme temperatures
Drive Pilot (Mercedes)	Level 3 automation on highways at low speeds	No conclusive studies found	Adverse weather, unpaved roads, poor GPS reception, technical failures
Parking Assistance	Assists driver with parking maneuvers	No conclusive studies found	Limitations of sensors
Rear Cross Traffic Alert	Alerts driver to cross traffic when in reverse	No conclusive studies found	Reduced functionality in angled parking

Section 2.4 Current Market

This section briefly reviews current market conditions and research on the timeline for widespread adoption of fully autonomous vehicles to set expectations on when ADAS technologies may evolve. Mercedes-Benz' Drive Pilot System, classified as a Level 3 conditional automated driving system, has been available in Germany since May 2022 as an add-on package for two models, namely the electric EQS and fuel-powered S-class (Mitropoulos, 2022). In early 2023, after complying with the requirements of Nevada Section 482A (2021) for Autonomous Vehicles, the system was approved for use in the United States, up to a speed of 40 miles/hour (64 km/hour). Mercedes-Benz was the first automotive company to meet the legal requirements of UN-R157, a set of regulations that concern the approval of vehicles with regard to their direct vision and maneuvering ability (UN, 2022). It is currently the only manufacturer in the world with approved Level 3 driving systems available to consumers for purchase. Recently, UN Regulation No. 157 (2022) was updated to extend automated driving up to 130 km/hour in certain conditions, effective January 2023. While some researchers are optimistic about the rate at which vehicles will become automated such that they are able to replace most driving tasks (Arbib & Seba, 2017; Johnson & Walker, 2016; Keeney, 2017), others believe there to be many technical obstacles that

prevent autonomous vehicles to operate reliably in all normal conditions (Leonard et al., 2020; Norton, 2021). With these vehicles also relying on appropriate public infrastructure that usually comes at a high financial cost, policymakers are important stakeholders in the process (Papa & Ferreira, 2018).

Integrating Level 3 automated driving systems in the automobile market has numerous benefits, some of which are as follows. According to Ye and Yamamoto (2019), safety is a primary benefit due to the potential of the technology to reduce road accidents. Shi et al. (2019) argue that such systems may increase road capacity, thereby enhancing efficiency and reducing traffic congestion. Liu et al. (2021) suggested fuel efficiency could be greatly improved, and Yao et al. (2021) highlighted the potential for significant reduction in harmful emissions. Kolarova et al. (2019) discuss the benefits related to travel time, which could be substantially reduced due to these automated systems. These systems also bring with them concerns in the field of cybersecurity (Li et al., 2018; Parkinson et al., 2017), and legality and ethics (Goodall, 2016; Himmelreich, 2018; Sparrow & Howard, 2017). Certain aspects of Level 3 automated driving systems' impacts remain uncertain and require further research. For instance, issues of accessibility have been studied by Milakis et al. (2018), Nahmias-Biran et al. (2021), and Papa and Ferreira (2018), who argue that while these systems could potentially increase accessibility, there are barriers to be addressed. Equity is another uncertain aspect, with Cohn et al. (2019) and Emory et al. (2022) exploring whether these systems could exacerbate or alleviate existing inequalities in transportation. Lastly, the economic implications are also uncertain, as noted by Alonso Raposo et al. (2018)and Clements and Kockelman (2017). They suggest that the economic impacts of widespread adoption of Level 3 automated driving systems could be transformative, but the exact nature of these transformations is yet to be fully understood. (Litman, 2023) conducted an analysis to suggest that most vehicles will not be autonomous at least before 2045, and it will be even longer before they are affordable. The fairly recent approval of the first-generation Level 3 vehicles in Europe and the United States reflects the nascent stages of the technology in terms of widespread adoption.

Section 3 – Driver Assessment in the Netherlands

Building on the technical details of ADAS from the previous section, this section offers a review of literature on current driver testing and licensing in the Netherlands. It lays the groundwork for future discussions on incorporating the safe use of ADAS into the practical driving exam. With a focus on the Netherlands, it begins with an analysis of the practical driving exam, clarifying how knowledge, skills, and safety behaviors are assessed. It then draws on interviews to shed light on the training requirements for examiners and their assessment techniques. The goal of this section is to give an overview of the current state of driver assessment in the Netherlands. This knowledge will help recommend improvements considering ADAS technologies and related skills.

Section 3.1 Getting a Driving License

Every motorized road user in the Netherlands is required to possess a valid driving license to operate a vehicle legally. Various types of licenses exist for different vehicle categories, including micro cars, mopeds, light mopeds, motorcycles, cars, lorries, buses, and tractors. The focus of this research is on vehicles in 'License Category B – Car and delivery van' as these comprise the majority of road traffic. The following legal provisions determine what is to be assessed in a driving test for a passenger vehicle (category B): Rules for requirements for the theory test of driving license category B (in Dutch) (2015), and Rules for requirements for the practical driving test of driving licenses categories B and BE (in Dutch) (2013). These two sets of rules are based on the Directive 2006/126/EC (2006) that outlines common minimum standards on skills, knowledge, physical and mental fitness of drivers. CBR (*Centraal Bureau Rijvaardigheidsbewijzen*) evaluates driving abilities, checks medical fitness for drivers, and oversees the expertise of individuals in the transport and logistics field, whereas the RDW (*Dienst Waverer*) and municipalities handle licensing, while the Minister of Infrastructure and Water Management regulates driving education and testing. To obtain a driving license, an individual must pass the theory exam before qualifying for the practical exam. Once the practical exam is passed and all other requirements are met,

the individual can collect their driving license in person at their local municipality. The assessment procedures part of the theory and practical exam are reviewed below.

3.1.2 Practical Exam.

The practical examination tests the examinee's ability to operate a vehicle safely in a variety of driving scenarios. It involves 35 minutes of driving, 10 to 15 minutes of which involve using a route navigation system. An accredited CBR instructor conducts the assessment, observing the examinee's command of the vehicle, their judgement and reaction to hazards, adherence to traffic laws, and communication with other road users. Any severe or dangerous mistakes disqualify the examinee from passing. Upon successful completion of the examination, the examinee becomes eligible to receive a Dutch driver's license. The examinee's evaluation follows the matrix in illustrated Figure 2, which is guided by the *Rijprocedure B* (CBR, 2023b). The document, translated to 'Driving Procedure' in English, outlines the steps for driving a vehicle safely and proficiently. It serves as the reference point for the evaluation criteria during a driving exam. The main objective of the test is to assessing a candidate's ability to drive safely and efficiently in varying traffic situations. Overall, it is the subjective judgement of the examiner that determines whether the candidate has shown a sufficient level of driving proficiency per the situations in the assessment matrix.

	Assessment aspects													
Situations	Failed	Preparation to take part in traffic, operating vehicle	Environment consciously driving	Adaptation to circumstance and decisive driving	Interest of other road users	Viewing Behavior	Giving Priority	Road position and place of maneuvers	Keeping distance	Speed	Reaction to traffic lights and instructions	Reaction to road signs and other road information	Use of signals and reaction to signals	Decelerating, accelerating, and stopping
Driving off														
Driving on straight and curved road sections														
Merging into/out of traffic														
Taking over other traffic and lateral movements														
Behavior at special road sections														
Special maneuvers														

Figure 2- Assessment matrix for driving examination by CBR translated to English. Adapted from (CBR, 2023b)

Road Safety Effects of Practical Driving Exam

Research linking driving test performance and crash risk is very limited as candidates who do not pass are not authorized to drive legally. Additionally, driving tests results may not be accurate indicators of safe driving after obtaining a license, considering that studies have shown males to outperform females on these tests (Crinson & Grayson, 2005; Mynttinen et al., 2011), despite being disproportionately involved in post-license accidents (SWOV, 2021). A study by Baughan et al. (2005) indicated that candidates who committed numerous minor errors during the practical driving exam experienced marginally higher crash involvement compared to those with fewer minor mistakes. However, the authors also mention that the increased involvement is attributed to the observation that the former group drives more frequently, thereby exposing them to greater traffic-related risks. More recently, an interview study of 13 driving instructors revealed they frequently possess an intuition regarding a learner driver's risky attitude, disregard for safety, or overconfidence (Watson-Brown et al., 2021). This is consistent with de Winter (2013) such that hazardous driving behavior during pre-license simulator training can serve as an indicator of self-reported traffic violations occurring up to 3.4 years after obtaining a license.

Section 3.2 Examiners

This section will review the role of driving examiners in the Netherlands. Examiners responsible for driver assessment in the Netherlands work for the Central Office for Motor Vehicle Driver Testing (CBR). Their primary role is to assess a candidate's competence in operating a vehicle by evaluating their practical skills following strict guidelines and standardized protocols. The process of becoming a driving examiner is rigorous to ensure high standards (CBR, 2023a). The first step requires the candidate to meet the desired education prerequisites which involve completing secondary education or an equivalent vocational qualification. The second step in the process is sending the application to CBR, after which the accepted applicants are invited to take a theoretical exam that tests their understanding of the traffic

laws and regulations in the Netherlands. The practical training program takes place over ten weeks and is described in more detail in the next section.

Practical Training

The training program to become a certified examiner is provided by the 'divisie Rijvaardigheid' (driving skills division) of CBR (2023a). The program involves achieving theoretical objectives through digital learning and self-study in week one. Week two has Exam T1 testing traffic legislation knowledge. Week three has Exam T2 assessing Vehicle Technology knowledge and communication skills training. Week four begins the practical module on driving skills, applying traffic laws, and recognizing desirable driving behaviors from Rijprocedure B. In week six, the vocational skills module starts, with a focus on skills like intervention, route instructions, and recognizing deviant behaviors through simulated exams. This ensures examiners gain the knowledge and skills to independently conduct exams. In week ten, Subtest T3 evaluates knowledge of Rijprocedure B and handling deviant behavior. After passing tests T1, T2, and T3, an oral exam on applying Rijprocedure B and the assessment system occurs. Passing the oral leads to the final test of conducting five 55-minute Category B driving exams while being assessed by an independent CBR auditor. Certified examiners need an experienced accompaniment for their first year and must stay current through continuous development. The training focuses on building theoretical knowledge and practical skills to become qualified independent examiners.

Due to the schedule and workload of driving examiners, it has been challenging for researchers to get access to them (van den Beukel et al., 2021). With an understanding of how examiner qualifications and training enable reliable candidate assessments, literature containing direct insights from examiners is now examined.

Insights from Driving Examiners in Netherlands

Three interviews with driving examiners from the Netherlands as participants have been reviewed to get insights on their assessment methods and their opinion on the current state of

technology in vehicles. Driessen et al. (2021) used semi-structured interviews to gather the views of 37 driving examiners on the prospect of data-driven assessment. Examiners were asked about the strengths and weaknesses of the current format of the driving test. To better understand the process of how examiners evaluate candidates, the authors also asked them about the role intuition plays when establishing a verdict. Examiner flexibility and the human aspect were strong aspects according to examiners, while lack of time and test variability were considered weak aspects of the current format of the driving test. Examiner flexibility is defined as the degree of freedom allowed for examiners to make a judgement and decision. Human aspect is defined as the comfort provided by examiners to candidates to make them less anxious. Test variability comprises variable traffic conditions due to the time of the day or testing location. Examiners also indicated that intuition plays a role in the evaluation process but not to the point of deciding the verdict. With the main focus of the research being data-driven assessment methods, there was no discussion of driver assistance systems.

Heikoop et al. (2020) conducted a focus group discussion of eleven driving examiners, using a semi-structured interview format, to gain insights into how meaningful human control could be applied to automated driving systems. The main points for which consensus was achieved were as follows:

i. The procedure for introducing new ADAS in the market is flawed due to a lack of information given to the consumer at this stage.
ii. Understanding the functionality of ADAS is important
iii. Automation surprise is a serious concern and safety issue
iv. Driver should not be relied on to monitor the systems

The other points that generated more discussion and split opinion were the human-oriented focus of the different levels of automation, and the potential formats of ADAS driver training.

Souman et al. (2021) conducted three interviews with driving examiners as a part of their project to quantify driving safety. It was found that the driving examination is done in a qualitative way, where

the examiner's opinion along with their experience leads to an assessment of whether the candidate is allowed to obtain a driver's license. Continuous training and education promote consistency between examiners along with strict selection and quality assurance procedures. With the main focus of the research being on quantifying driving safety, driver assistance systems were not discussed. The following section discusses the ways in which drivers interact with ADAS technology.

Section 4 – Driver Interaction with ADAS

This section describes the knowledge, skills, and behaviors that need to possessed and exhibited by drivers for safe operation of a vehicle and their evolution given the advancements in technology that partially or completely take over the driving task. First, the traditional driving task is discussed using appropriate models. Cognitive Models are used thereafter to highlight the change in the role of the driver due to increasing driver support and automation through technology. Finally, a set of skills that exhibit safe operation of a partially automated vehicle are compiled from literature. The following section will review several theoretical frameworks, each of which contribute to conceptualize the driving task.

Section 4.1 Theoretical Frameworks

Theoretical frameworks provide valuable cognitive constructs to analyze how driver psychology and behaviors are impacted by increased vehicle automation. Rasmussen's (1983) skill-rule-knowledge framework differentiates driving behaviors based on the degree of conscious control, ranging from automated skill-based actions to knowledge-based responses in novel situations. This allows for categorization of driving sub-tasks according to the driver's experience level. Michon's (1985) model complements this by categorizing driving into strategic, tactical, and operational levels of control over different timescales, from planning to physical vehicle control.

Combining these two frameworks, Hale et al. (1990) proposed using hierarchical task analysis to systematically determine the sequence of driving sub-tasks and the associated behavioral responses. The

combined Rasmussen-Michon model provides a means to link driver psychology to the level of automation in driving. Building on this foundation, Stanton and Young (2000) developed a model covering both cognitive and motivational psychological factors, including trust in automation. Heikoop et al. (2016) further showed mental workload as a key mediating variable affecting driver attention allocation and situation awareness with increased automation.

In summary, Rasmussen's skill-rule-knowledge categories and Michon's levels of control model together provide the most relevant theoretical framework for analyzing how driving tasks and behaviors change with vehicle automation. The integrated model facilitates analyzing sub-tasks and psychology factors based on the driver's experience and the timescale of vehicle control.

Section 4.2 Impact of Automation on Driving Task

Researchers widely agree that increasing vehicle automation transforms not just the tasks assigned to human drivers, but also the skills and knowledge needed to perform them (Bainbridge, 1983; Maurer, 2016; Parasuraman & Riley, 1997; Strauch, 2018). As automation increases, the driver's role shifts from active operation to more passive monitoring, increasing workload due to more cognitive tasks involved in supervising automated systems (Banks & Stanton, 2019). Quantitative frameworks reveal negative trends in skill- and rule-based behaviors as automation increases, although knowledge-based behaviors may initially increase up to Level 3 before decreasing (Heikoop et al., 2019).

Overall, research suggests driving does not necessarily become easier with automation (Hoc et al., 2009; Strauch, 2018; Young & Stanton, 2007). Drivers take on more supervisory, monitoring roles rather than active control. Researchers have analyzed these changing roles using various frameworks, finding emerging skills include abilities to properly calibrate trust, manage attention, and maintain situation awareness regarding the automation (Banks & Stanton, 2019; Kaber & Endsley, 2004; Spulber, 2016; van den Beukel et al., 2016). As vehicle automation increases, drivers are relieved of some operational demands but face new cognitive challenges to supervise semi-autonomous systems.

Section 4.3 Skills Required

Spulber (2016) categorized the skills required for using automated vehicle technology, converted from the NHSTA taxonomy to equivalent SAE Level and denoted in brackets for easier understanding, as follows:

i. Skills needed to monitor the normal functioning of automated driving systems,

   a. Driving automated vehicles will require better supervision and intervention skills compared to manual control and maneuvering skills.

   b. The supervision role, especially for [SAE] Levels 2 and 3, will require skills in terms of automation coordination (sharing information), automation cooperation (being aware of and supporting each other's goals), and automation collaboration (working on a shared project).

   c. Drivers will need to adapt to the different levels of automation and understand the distribution of tasks between automation and manual control for each level, i.e., familiarity with the electronic functions of automated vehicles will be required for all drivers using [SAE] Levels 1 to 3.

   d. Operators will need to know when and how to interact with automated driving systems. Each of the [SAE] Levels 1 to 3 will require different skills from drivers, especially in terms of situational awareness.

   e. Drivers will need to master the techniques for transitioning from automation to manual control, as well as between different levels of automation.

   f. Drivers will need to develop the capacity to maintain a constant level of awareness of the performance of the automated vehicle and the environment while, at the same time, performing secondary tasks with a variety of difficulty and attention requirements.

   g. Drivers should know when it is safe to engage in secondary tasks. For [SAE] Level 3 vehicles, drivers must develop the ability to resume manual operation of the vehicle in a timely manner when the system requires it, as they are not required to constantly monitor the roadway.

h. Obtaining the skills required for driving an AV is a more complicated process compared to that for a manual control car.

ii. Skills needed to respond to failures or limitations of automated driving systems.

a. Drivers may need to be aware of the proper functioning of ADS features [Level 3], in order to be able to recognize automation errors.

b. When shared authority between humans and automation is required [SAE Levels 1-3], the driver must fully understand the capabilities and limitations of the ADS and be aware of how the system is operating in case intervention is required. Failure to do so may lead to crashes, irrespective of whether they are human or machine induced.

c. Drivers must have an accurate understanding of the normal functioning, limitations, and potential failures of the automated driving system to avoid mode confusion, a situation in which the operator is uncertain about the status or behavior of the automation.

d. Drivers will need to maintain a sufficient level of alertness to identify automated driving system failures and react to them in a timely manner.

e. Drivers must know when it is appropriate to take manual control of a vehicle and how to do so successfully when faced with an automation failure.

f. To know how to reach when faced with automation malfunctions or limitations, drivers must maintain a skill level that allows them to manually perform the tasks executed by automation (lateral and longitudinal control) as well as emergency maneuvers (crash avoidance).

g. Drivers need to be prepared to take manual control of a vehicle when least expected and in some of the most dangerous and critical situations, a well-known paradox of automation made popular by Bainbridge (1983).

Banks and Stanton (2019) included the following monitoring tasks as required by a driver to monitor the behavior of the automated system, the road environment and anticipate the behavior of other road

users, as well as being prepared to regain control of the vehicle if necessary. Compliance with rules, journey, steering, vehicle speed, vehicle systems, road for hazards (bends/gradient), response to environment, directional control, and preparing to take back control. Acquiring the knowledge and skills required to operate new generations of partially automated vehicles is not a straightforward process and researchers have long explored ways in which this gap can be closed. Apart from the responsibility of automakers to design these systems in a certain way and uniformity among manufacturers, improving driver education and training are seen as an important component to bridge this gap.

Section 5 – Driver Education and Training

This section describes the ways by which drivers first learn about ADAS and discrepancies with their preferred methods of learning. By reviewing studies that analyze different learning methods, an overall awareness and understanding of ADAS among new vehicles owners will be gathered. The role of driver training to fill the described knowledge gap in driver's understanding of ADAS will then be reviewed. To culminate, literature that proposes training standards and guidelines which incorporates the advancements in technology will be summarized.

Section 5.1 Learning about ADAS

Research demonstrates that providing drivers with conceptual knowledge of ADAS early on is beneficial. However, there remain gaps in driver understanding of these technologies. Formal training programs represent one important way to address the knowledge gaps surrounding ADAS. Studies have found that training which explains the underlying logic and functionality of ADAS can improve driver performance with them (Payre et al., 2017). Interactive learning opportunities that actively engage drivers have been shown to support the development of more advanced mental models and appropriate trust in automation (Ebnali et al., 2019). However, more research is still required to understand how skills from training transfer to realistic automated driving scenarios.

Other studies indicate fairly limited training effects on driving behavior, attitudes, and knowledge compared to the impacts of actual hands-on driving experience with ADAS over time (McDonald et al., 2017; Noble et al., 2019). Nevertheless, video-based instruction has demonstrated promise for improving ADAS understanding and safety among older adults (Zahabi et al., 2020). Driving simulators also show potential to enhance interaction with and adoption of new ADAS technologies (Sætren et al., 2018). Overall, formal driver education and training programs represent a key opportunity to address knowledge gaps and improve understanding of ADAS capabilities and limitations. However, more research is still needed on optimizing these programs and transferring knowledge to real-world driving contexts. The next section reviews applicable training standards and guidelines for operating partially automated vehicles

Section 5.2 Training Guidelines

Manser et al. (2019) developed training protocol guidelines that lists the skills and knowledge drivers should be trained on when using ADAS. The authors recommend that drivers of vehicles with ADAS equipped should be trained on the five items. First, the purpose of using ADAS, including its risks and benefits. Second, understanding the different levels of ADAS, including capabilities and the driver's level of responsibility at each level. Third, transitioning between ADAS and manual mode and handling critical situations, including system malfunctions. Fourth, being familiar with system components and placement, including the sensor and radar camera. And fifth, understanding the limitations of ADAS, including adaptive cruise control, lane-keeping assistance systems, and emergency brake assist. The authors recommend training protocols that emphasize the importance of driver attentiveness, especially when using ADAS. They suggest covering diverse techniques in widely available voluntary programs created by various stakeholders.

Casner and Hutchins (2019) also proposed driver training standards for partially automated cars. The authors divided the knowledge a driver should possess to operate partially automated cars into

three categories, namely, automation, drivers, and the driving task. “How to recognize an inoperative camera or sensor”, “How the driver can tell which functions are active at any given tie”, and “How each automation function can be activated and deactivated by the driver”, are few examples of items that fall under the category of automation. “Vigilance drops off quickly (~15–20 min) because of fatigue and mind wandering”, “Vigilance tends to wane when we delegate control to an automated system”, and “Drowsiness becomes more of a factor when control is delegated to automation”, are few examples of items that fall under the category of drivers. “The car cannot drive itself, for any length of time “, “The driver will likely be held responsible for whatever happens”, and “The automated features are tools available at your service, should you decide to use them”, are few examples of items that fall under the category of the driving task.

Merriman et al. (2021) identified eight interrelated themes in current manual vehicle driver training: attention, situational awareness, trust, workload, speed of processing, attitudes and personality, procedural skills, and hazard/risk perception. ‘Trust’, which did not exist in current manual vehicle driver training literature, was added as an additional theme with automated vehicles in mind. The authors argue that a multifaceted approach to driver training, which combines training both manual and automated vehicle driving skills, is required to address the complex challenges associated with automated vehicles.

Section 5.3 Policy & Latest Developments

Researchers and policymakers both call for updating training and testing practices to account for developments in technology, referring to it as an important milestone for the safe operation at all levels of automation (Polders et al., 2017; Roemer, 2021; van Driel et al., 2019). The new EU (2023) proposal to update driver licensing rules contains a new guideline for “Knowledge, Skill and Behaviour for driving a power-driven Vehicle” – ‘Drivers should have sufficient knowledge on the usage of advanced driving assistance systems and of other automation aspects of a vehicle.’ This initiative by policymakers is a step

in the right direction. However, the use of the term ‘sufficient’ is vague and vastly subjective without supplementing standards. Although due to the limited research regarding what behaviors are attributed to proficient control of partially automated vehicles and what to include in driver training programs, it is understandable. This comes after EU Regulation 2019/2144 (2019) which aims to significantly reduce deaths and serious injuries on EU roads by mandating a range of ADAS, went into effect on July 6, 2022, and mandates certain ADAS be installed on new car models. In context of the Netherlands, Roemer (2021) recommended that the driving education system needs to move from a test-led system to a test and education-driven system, with similar recommendations by Helman et al. (2017) from a broader European perspective. Dijsselbloem and Zouridis (2019) and Vlakveld (2019) also address the need for specific training to bridge the gap that ADAS creates between a drivers' proficiency in engaging with ADAS technology and their responsibility for its safe operation. The longer this gap remains unaddressed, the more likely a situation in the future where highly automated cars have not been able to achieve the safety potential initially promised Steen et al. (2020). The next section will explore literature that is specific to ADAS and the practical driving exam.

Section 6 – ADAS in the Practical Driving Exam

This section will review literature that examines ways in which drivers can be evaluated on their knowledge, skill and behavior of ‘ADAS’ during the practical driving exam. First, the extent of inclusion of ADAS in the practical driving exam of countries around the world will be reviewed. Thereafter, literature which discusses methods to assess ADAS competency will be examined. Finally, the challenges in incorporating ADAS evaluation into the driving exam according to researchers and policymakers will be summarized.

Section 6.1 Current State

On the date of reporting, there were no countries that evaluate a driver’s knowledge, skill, or behavior in relation to the list of ADAS discussed in this research. Per the results of the literature search,

only three countries were identified as taking definitive steps to integrate ADAS into the driving exam. The three countries were the Netherlands, United States, and Australia. With the research questions in mind, this section will focus on the Netherlands and review the latest documents which discuss ADAS.

The Netherlands

In January 2023, CBR released an update to *Rijprocedure B* which for the first time includes guidelines to evaluate drivers on their use of ADAS. The CBR (2023b) guidelines are listed below:

(1) For 'driveability, operation/control and environmentally conscious driving':

i. Prior to driving, the driver checks which driving assistance systems in the car directly affect driving and how they work.

ii. The driver checks whether the sensors and cameras are sufficiently clean prior to a trip. He remains alert to the best possible operation of the driving assistance systems. The driver acts appropriately to anomalies.

iii. The driver uses the settings of driver assistance systems in a way that contributes to the most desirable driving behavior according to this driving procedure.

iv. The driver also adopts an active driving posture when driving with assistance systems adopts an active driving posture, easily taking over the driving task from the car. In doing so, he keeps an eye on the traffic situation and driving assistance systems at all times. The driver therefore distracted from his driving task and responsibility.

(2) For 'participating in traffic correctly and safely':

i. The driver continuously monitors the car and the traffic situation while driving, also when using driver assistance systems. (incorporate wording of this into matrix ; continuously monitors/attentive ; fine something more specific and less open for interpretation.

ii. The driver himself perceives the situation directly. He consciously chooses whether to be supported by driver assistance systems.

iii. According to this driving procedure, the driver reacts to the information/warnings from the driving assistance systems.

iv. The driver switches the driving assistance system on or off when the situation or the driving assistance system requires it. By situation is meant road, weather, traffic and driver.

Currently, candidates in the Netherlands are allowed to voluntarily utilize ADAS (except automated parking) but will only be evaluated on their ability to apply and manage these systems in relation to the desirable driving behavior as described in Rijprocedure B (CBR, 2015).

In a prominent study of ADAS use in driver training and exams in the Netherlands, Vlakveld and Wesseling (2018) gathered insight into the topic from 1047 driving school owners and 272 driving test B examiners. Findings of particular relevance are listed below:

i. Most driving school owners found instructions on parking sensors, cruise control, and reversing cameras beneficial, while few consider teaching uncommon systems like Autopilot to be valuable.

ii. Most driving school owners found parking sensors, cruise control, and reversing cameras useful to be taught, but few found teaching rare systems like Autopilot useful.

iii. Only 30% of driving school owners have planned lessons specifically for ADAS, despite teaching and using it in lessons.

iv. Most driving examiners do not know which ADAS are present in the lesson car, and candidates seldom inform them.

v. Driving examiners unanimously agree that students should be trained in common ADAS, and a majority think theory exams should include questions about them.

Section 6.2 Assessing Safe Use of ADAS

Literature that assesses driving skills with respect to ADAS systems has been ongoing since ADAS was introduced into the market and will continue to evolve as more technologically advanced ADAS are

made available across more markets. Although, research which evaluates drivers on their use of ADAS from the perspective of a driving exam is very limited. Only one source of literature from the Netherlands was discovered during the literature search on this topic.

van den Beukel et al. (2021) evaluated the impact of ADAS such as adaptive cruise control on driving proficiency by conducting a field experiment with novice drivers based on a developed framework. The authors found that the use of ADAS, specifically adaptive cruise control, can have a negative influence on self-initiated maneuvers such as lane changes, but may improve adaptations to maneuvers initiated by other road users like merging in traffic. By compiling and filtering a list of relevant skills and behavioral aspects from literature and feedback from driving instructors, a list with 49 separate aspects, each addressing a relevant skill or behavior was created to be included in the framework. This list was restructured based on which behavioral aspects are relevant to the driver's role to supervise ACC within the predefined use case of highway cruising. The resulting 5 categories part of the D-Brief framework were as follows – Operational Control, Speed and Anticipation, Perception: Viewing Behavior, Perception: Traffic and Road Situation, and Driver's Controllability of ACC. The results showed that D-Brief revealed significant differences between manual driving performance and driving with ACC. The framework was developed to add to the existing assessment matrix for driving proficiency (Figure 2) but due to the time frame of the field test, it was not able to be tested by driving examiners and was considered a limitation to the research. Thus, evaluating the framework with driving examiners is an important recommendation made by the authors.

Building upon the comprehensive foundation laid out in this chapter, the methodologies adopted for this research are delineated and justified in Chapter 3, taking into account the identified gaps and challenges.

Chapter 3 – Methodology

3.1 Introduction

This chapter outlines the methodology undertaken to address the research question “How can driving examiners effectively evaluate safe use of Advanced Driver Assistance Systems by a candidate during a practical driving exam?”. A primary qualitative approach, enriched with quantitative data, was undertaken to comprehensively investigate this real-world issue. Qualitative methods were prioritized to enable an in-depth understanding of examiner perspectives and real-world complexities through first-hand observations and discussions. While a quantitative approach may have allowed for more breadth, a qualitative approach is better suited to gain nuanced insights on a topic with limited research.

This chapter begins with an overview of the research design. It then details the participant selection criteria and demographics. Next, it describes the development of the ADAS Assessment Matrix, a key research component. The data collection and analysis techniques are then outlined. Finally, the ethical provisions undertaken to comply with professional and legal standards are noted.

3.2 Research Design

The iterative development of the 'ADAS Assessment Matrix' was identified as foundational to this research and subsequently the chosen research design. This process is depicted in Figure 3 and was validated by driving examiners through case studies and interviews. A primarily qualitative approach was chosen, enriched with quantitative data where necessary, to ensure that the intricacies and nuances vital for understanding the safe use of ADAS during driving exams was captured. Due to the flexibility offered by qualitative research, a detailed examination of real-world ADAS interactions, examiner perspectives, and assessment gaps was facilitated. When quantitative data was integrated, not only was additional rigor provided, but a holistic approach to the research questions was also ensured.

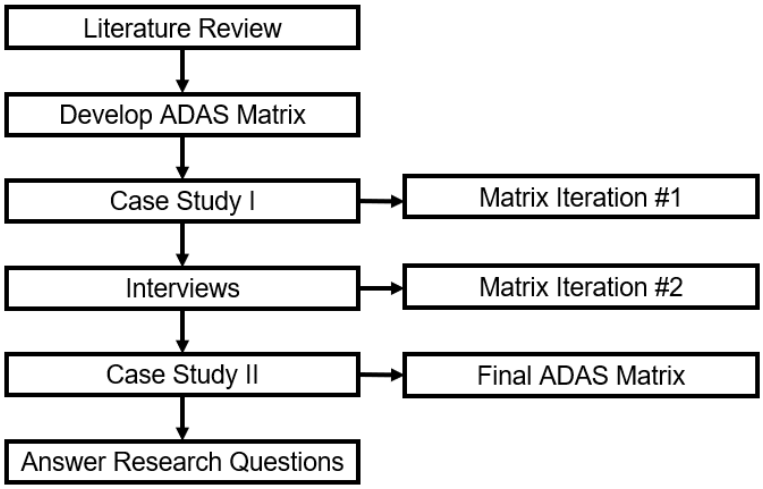

Figure 3-Overview of the Iterative Research Design for the Development and Validation of the ADAS Matrix

The following qualitative methods were incorporated into the research design:

- A Literature Review was conducted. In this step, existing practices, methodologies, and literature related to ADAS, driver assessment, and driving exams were reviewed. This ensured that the developed ADAS Assessment Matrix's was both informed, and devoid of repetitive efforts.
- In the first Case Study, mock driving exams were observed directly. Real-world testing intricacies were witnessed firsthand, which led to the creation of the first iteration of the matrix.
- Semi-Structured Interviews were conducted with three driving experienced examiners. Insights into driver-ADAS dynamics and evaluation practices were gathered, leading to the second iteration of the matrix.
- In the Second Case Study, the matrix was tested and validated in real-world settings by observing mock driving exams again. Data was gathered, which then refined the matrix leading to the final ADAS Assessment Matrix proposed by this research.

Case studies, as suggested by Yin (2017), are suitable for in-depth examination of real-world scenarios and provide holistic insights by drawing from various sources. This methodology was found to align with the study's goal of evaluating the safe use of ADAS during practical driving exams.

Interviews with driving examiners were deemed essential as insights into the ADAS Assessment Matrix and its integration into driving exams were gathered. This approach allowed for flexibility as suggested by Brinkmann and Kvale (2015). While surveys or focus groups could have been used, they might not capture the depth that interviews can provide. For instance, nuances might be overlooked in surveys, the rationale behind decisions might not be captured in observational studies, and individual insights might be overshadowed in focus group discussions. With the research design established, details regarding the participants involved in this study will be discussed in the next section.

3.3 Participants

Participants for this research were driving examiners from the Netherlands and employees of CBR. An invitation to participate was dispatched to the exam manager coordinator by e-mail, who subsequently relayed it to potential driving examiners. Driving examiners were specifically selected as the priority participant group because of their direct role in conducting practical driving tests and expertise in evaluating drivers. Their first-hand insights are critical for developing an effective ADAS assessment tool intended for their use. The participant group included:

- Four driving examiners with experience ranging from 15 to 30 years
- One driving examiner-in-training
- One CBR staff member in a simulated candidate driver role.

Every participant received a comprehensive briefing about the study's objectives, procedures, confidentiality protocols, potential risks, and benefits. Written consent was secured from all participants prior to their involvement, with the consent forms archived in Appendix D. Having covered the participant details, the next section describes the development process for the ADAS Assessment Matrix.

3.4 ADAS Matrix Development

The ADAS Matrix will serve as a tool for driving examiners to evaluate drivers on their safe use of ADAS. The steps taken to develop the initial matrix are detailed below.

Step 1: Selecting the ADAS

Given the variety of ADAS in current vehicles, the first step in developing the matrix was selecting which ADAS to evaluate during the driving exam. Based on the ADAS catalog in Section 2.3 of the literature review, a filtering process was applied in line with the research theme. The ADAS selected for were chosen based on the following: criteria 1 - association with operational control; criteria 2 - ethical considerations; and criteria 3 - availability of cars for driving exam.

Table 2- Filtration Process of the Cataloged ADAS per the Listed Criteria. Fields with 'x' do not meet the criteria.

ADAS Functionality	*Criteria 1*	*Criteria 2*	*Criteria 3*
Longitudinal Control of Vehicle			
Forward Collision Warning (FCW)			
Automatic Emergency Braking (AEB)			
Pedestrian/Cycle/Object Detection		x	
Adaptive Cruise Control (ACC)			
Intelligent Speed Assist (ISA)			
Lateral Control of Vehicle			
Lane Departure Warning (LDW)			
Lane Keeping Assist (LKA)			
Blind Sport Warning (BSW)			
Combination of Long. & Lat. Control of Vehicle			
Autopilot (Tesla)			x
Drive Pilot (Mercedes Benz)			x
Special maneuvers			
Parking Assistance			
Rear Cross Traffic Alert			

With all ADAS using sensors, cameras, or a combination of the two to assist with the driving task, limitations of the sensing technologies were also selected for evaluation. Table 3 shows the final list ADAS selected for the initial matrix.

Table 3-ADAS Selected for the Initial ADAS Matrix

Sensors & Cameras	Parking Sensors	Blind Spot Warning	Lane Keeping Assist	Lane Departure Warning	Forward Collision Warning
Maximum Advisory Speed Limit	Intelligent Speed Assist	Cruise Control	Adaptive Cruise Control	Automatic Emergency Braking	

Step 2: Identifying Driver Behavior to Evaluate

The second step in the research design was identifying the ADAS-related driver behaviors that exhibit safe ADAS use. Section 4.3 of Chapter 2 reviewed the skills required for using automated vehicle technology. Section 5.2 of Chapter 2 reviewed training protocol guidelines that lists the skills and knowledge drivers should be trained on when using ADAS. Section 6.2 of Chapter 2 reviewed the list of behavioral aspects relevant to the driver's role to supervise ACC. Section 6.1 of Chapter 2 reviewed the guidelines to evaluate drivers on their use of ADAS listed by CBR. Table 4 lists the sources from which the driver behaviors for the initial ADAS matrix were selected.

Table 4-Sources for the Driver Behaviors Selected for the Initial ADAS Matrix

Author (Year)	Title	Organization
Spulber (2016)	Impact of Automated Vehicle Technologies on Driver Skills	Michigan Department of Transportation (MDOT)
Manser et al. (2019)	Driver Training Research and Guidelines for Automated Vehicle Technology	U.S. Dept. of Transport (US DOT)
van den Beukel et al. (2021)	Assessment of Driving Proficiency When Drivers Utilize Assistance Systems	Transportation Research Interdisciplinary Perspectives
CBR (2023b)	*Rijprocedure B*	*Centraal Bureau Rijvaardigheidsbewijzen*

The four listed sources were compiled and filtered to include only the key driver behaviors that exhibit safe ADAS use. Table 5 lists the specific ADAS-related behaviors and the source(s) from which they were extracted.

Table 5-Detailed Sources for the Driver Behaviors Selected for the Initial ADAS Matrix

ADAS-related driver behaviors	*Source(s)*
Checks condition of sensors and cameras	CBR (2023b); Manser et al. (2019)
Clarifies operational limits of ADAS	Manser et al. (2019); Spulber (2016); van den Beukel et al. (2021)
Activates and deactivates successfully (if required)	Manser et al. (2019); Spulber (2016); van den Beukel et al. (2021)
Displays desirable driving behaviour when using ADAS	CBR (2023b)
Takes over manual control successfully (if required)	Manser et al. (2019); Spulber (2016); van den Beukel et al. (2021)
Considers other road users and environment when ADAS in use	CBR (2023b); van den Beukel et al. (2021)

Step 3: Putting Together Matrix

The third step involved developing the ADAS assessment matrix by compiling the results from the previous two steps in a format that can be easily interpreted by examiners. Each matrix column represented a specific ADAS system, and rows denoted requisite driver behaviors for safe use of ADAS. Each cell in the matrix, therefore, provided a unique combination of an ADAS system and a specific driver behavior associated with it.

Step 4: Modifying Matrix Structure

The fourth step focused on the refinement and validation of the ADAS assessment matrix. This will be done by conducting case studies and interviews with examiners as participants. Now that the development of the ADAS Matrix has been detailed, the next section summarizes the data collection methods used to iterate and validate the matrix.

3.5 Data Collection

Data was collected three times during the course of the research. In an initial case study, a practical driving exam in the Netherlands was experienced first-hand in a controlled setting. Through three interviews, the intricacies of the exam and integration of ADAS into it were thoroughly explored.

Finally, the developed and iterated ADAS matrix was tested for its efficacy in a real-world scenario. These three steps allowed a comprehensive analysis of the research question, with each part described below.

Case Study I

The objective of this case study was to examine the use of ADAS in real-world driving situations encountered during a practical driving test and to validate the ADAS Matrix. At the CBR Exam Center in Leusden, Netherlands, two mock driving exams were administered. An experienced examiner undertook the role of a candidate driver, replicating common behaviors exhibited by typical candidates. An evaluation of the experienced examiner was carried out by the examiner-in-training from the passenger seat. This approach is traditionally employed during the examiner training program to acquaint new examiners with a range of candidate behaviors.

The 2020 Kia Ceed was the vehicle used for this study. Observations of the two mock driving exams were noted from the vehicle's rear seat. The driving examiner was prompted to engage ADAS when deemed safe, with no preliminary instructions provided to the examiner-in-training. Before the initial trial, a copy of the ADAS matrix was handed to the examiner-in-training, and any uncertainties were addressed. Throughout the two drives, systematic notes concerning ADAS usage were documented on paper. These notes aimed to facilitate discussion and corroborate findings with participants post-drive. In addition, the examiner-in-training completed the developed ADAS assessment after both the drives. The collection of exam observations, feedback on the devised matrix, and subsequent discussions culminated in the first iteration of the matrix.

Interviews

Semi-structured interviews were conducted with three driving examiners to understand driver evaluation and current testing protocols. The interview guide, found in Appendix A, was formulated based on principal themes from the literature review, emphasizing ADAS use and driver evaluation

practices. The interview guide was developed based on recommendations by Jacob and Furgerson (2012) on constructing focused interview protocols for qualitative research. Background questions gauged the examiners' experience, while open-ended ones allowed them to delve into their expertise. The guide was refined to emphasize pertinent topics which are not present in existing literature. This approach ensured both structured queries and room for open discussions. Core areas of inquiry included existing testing protocols, ADAS safe usage, implementation strategies, anticipated challenges, and potential effects on aspirant drivers.

The interviews, conducted via Microsoft Teams and lasting 40 minutes, followed a three-part format: 1) examiner backgrounds and perspectives, 2) feedback on the ADAS matrix, and 3) challenges, theory testing, and suggestions for modifying driving criteria. With participants' consent, interviews were recorded and transcribed verbatim for analysis.

Case Study II

Two mock driving exams were conducted with an examiner and a participant who assumed the role of a candidate driver, at the CBR Exam Center in Arnhem, Netherlands. The goal was to gather feedback on the efficacy of the ADAS Assessment Matrix in a real-world setting. The location of the tests, while familiar to the examiner, were unknown to the candidate driver. The researcher acted as an observer, recording ADAS activations and any associated observations.

The 2021 Lynk & Co 01 was used for this study, a more technologically advanced vehicle compared to the Kia Ceed used in the first case study, thereby expanding the potential ADAS features for examination. The driver was encouraged to engage ADAS as much as possible, but only when comfortable doing so. The ADAS Assessment Matrix was presented to the examiner before the experiment, allowing any questions to be addressed by the researcher.

After each run, both the participants were asked to rate each field of the ADAS matrix on a five-point Likert scale, providing numeric measures of observability and relevance to complement the qualitative observations noted during the drives. In addition, post-test discussions between the parties and researcher were held after each run to corroborate specific situations observed during the ride. The objective of these discussions was to delve further into the examiners' perceptions of the challenges faced during the run and to explore potential enhancements to the procedure. At the end of two runs, both participants were asked to fill in a questionnaire. The goal of supplementary questionnaires was to gather additional quantitative data on the examiner's perspective of the matrix's effectiveness and improvements, plus the driver's background and term interpretations. This helped further contextualize the qualitative findings.

For the driver, the questionnaire was developed to gather data on their driving experience, knowledge of ADAS systems, and their interpretation of terms used in the ADAS Matrix. For the examiner, the questionnaire collected their feedback on the difficulty, effectiveness, and suggestions for improving the ADAS Assessment Matrix. The questionnaire also gathered the demographics of the participants, along with other information which could help provided more context for the data collected. This second case study, therefore, while sharing foundational methodologies with the first, added novel elements that specifically aimed to test and gather feedback on the ADAS Assessment Matrix. With the data collection outlined, the next section explains the analytical techniques used to examine the collected data.

3.6 Data Analysis

The data analysis involved a systematic qualitative review of field notes, interview transcripts (Appendix B), and post-exam discussions with examiners. For the first case study, the field notes were analyzed to extract salient themes on ADAS usage and assessment. For the interviews, thematic analysis

was used to identify key themes and appropriate sub-themes. For the second case study, the focus was on synthesizing insights from the qualitative observations, supplemented by feedback from the participants and post-exam discussions.

Case Study I

The data analysis involved a qualitative synthesis of extensive observational field notes from the mock driving exams. The timestamped notes contained real-time documentation of ADAS usage, difficulties, and examiner conversations. The notes were reviewed to extract relevant information per the research objectives on ADAS usage and assessment. These excerpts were analyzed to identify salient themes reflective of major takeaways rather than granular details.

Interviews

The interview transcripts (Appendix B) were analyzed using thematic analysis, following the steps outlined by Braun and Clarke (2006). The first step in the process was the familiarization with the data through initial observations. The second step involved the generating of initial codes based on the data. The third step was the searching for themes that emerged from the coded data. The fourth step was the reviewing of the potential themes and sub-themes that had been identified. The fifth step was the defining and naming of the main overarching themes. The final sixth step was the reporting of the results of the thematic analysis. The results from each step can be found in Appendix C.

Case Study II

The data analysis involved synthesizing the extensive qualitative data collected to identify key themes related to ADAS usage and assessment challenges. The observational field notes from the mock exams provided rich qualitative insights into behaviors and assessment complexities in real-world contexts. Follow-up discussions validated and expanded on these observational insights, adding practitioner perspectives. The questionnaire supplemented this qualitative data with quantitative ratings

on the assessment matrix. Questionnaire results often correlated with observed difficulties, connecting the qualitative and quantitative data.

In summary, qualitative synthesis of the extensive field notes was optimal for observing key patterns and issues from the mock exam contexts. Qualitative data from discussions and interviews provided important supplemental perspectives to validate and build on the observational insights. This integrated qualitative analysis delivered a robust, multi-faceted characterization of ADAS assessment challenges grounded directly in practitioner experiences. The analytical approach aligned closely with the descriptive, exploratory aims of the research. With the qualitative data analysis processes covered, the final section will summarize the ethical protocols followed to ensure participant protections.

3.7 Ethical Considerations

This study was conducted in accordance with ethical guidelines for human subjects research. The research protocol was approved on 27th June 2023 by the TU Delft Human Research Ethics Committee (HREC) prior to data collection (application number 3152). Participation was completely voluntary. Prior to data collection, participants were provided with an information sheet detailing the nature and purpose of the study, what participation would involve, potential risks and benefits, privacy and confidentiality protections, and their right to withdraw at any time without penalty. Written informed consent was obtained from all participants. To protect privacy and confidentiality, all data was deidentified by assigning numeric codes to participants. Deidentified data was stored securely on password-protected devices and university servers, with access limited to the researcher. Identifying information was stored separately from study data. The study was considered low risk; however, participants were informed they could contact the researcher or ethics committee if they experienced any distress or discomfort. There were no additional ethical approvals required for the specific location

or population studied. Participants were fully debriefed upon completion of the study. They were provided with the researcher's contact details should they have any questions or concerns.

With the appropriate ethical procedures and approvals in place, the research methodology outlined in this chapter were enacted, with the obtained results detailed in the following chapter.

Chapter 4 – Results

4.1 Introduction

The results presented in this chapter address the research question guiding this study by outlining the development and validation of an ADAS Assessment Matrix intended to assist driving examiners in evaluating candidates' safe use of ADAS during practical exams. As detailed in the Methodology chapter, the research design involved an initial case study observing mock driving exams to gather real-world insights into ADAS usage and assessment complexities. Building on these observations, semi-structured interviews were conducted with examiners to further refine the matrix. A second case study was then carried out to test the efficacy of the matrix and gather additional feedback. Through this iterative, qualitative approach of observations, interviews, and field testing, the ADAS Assessment Matrix was progressively enhanced to optimize its functionality for driving examiners. The results obtained at each stage of this process will now be presented in chronological order as listed below:

1. The initial ADAS Assessment Matrix which is based on literature.
2. A case study which served as the first validation of the ADAS Assessment Matrix
3. The first iteration of the ADAS Matrix based on the results of the first case study
4. Thematic findings from interviews with examiners
5. Feedback from the same examiners on the ADAS matrix, serving as the second validation of the ADAS Assessment Matrix
6. The second iteration of the ADAS Assessment Matrix based on the results of the interview
7. A second case study to assess the ADAS Assessment Matrix’s real-world applicability
8. The final ADAS Assessment Matrix proposed by this research

4.2 Initial ADAS Matrix

Table 6-Initial ADAS Assessment Matrix, Developed After the Literature Review

ADAS Assessment Matrix	Assessment Notes										
	Triggered during desirable driving behavior, evaluate per situation			Not indicative of desirable driving behavior, evaluate per situation					Only if used		Emergency
Driver Behavior & ADAS Systems	Sensors & Cameras	Parking Sensors	BSW	LKA	LDW	FCW	Max Advisory Speed Limit	ISA (Passive)	Cruise Control	ACC	AEB
Checks condition of sensors and cameras											
Clarifies operational limits of ADAS											
Activates and deactivates successfully (if required)											
Displays desirable driving behavior when using ADAS											
Takes over manual control successfully (if required)											
Considers other road users and environment when ADAS in use											

The initial ADAS Assessment Matrix developed for this study contained 10 columns representing the following ADAS systems selected for assessment: sensors and cameras, parking sensors, blind spot warning (BSW), lane keeping assist (LKA), lane departure warning (LDW), forward collision warning

(FCW), intelligent speed adaptation (ISA), adaptive cruise control (ACC), and autonomous emergency (AEB) braking were the ADAS systems included in the matrix. These ADAS were chosen based on their relevance to vehicle control tasks, safety impacts, and feasibility of evaluating within the constraints of a practical driving exam. The matrix had 6 rows capturing essential driver behaviors for safe ADAS operation: The columns captured behaviors such as checking the condition of sensors and cameras, clarifying the operational limits of ADAS, successfully activating and deactivating ADAS, displaying appropriate driving when ADAS is engaged, successfully taking over manual control when needed, considering other road users when ADAS is active.

Each cell in the matrix denotes the intersection between an ADAS and a required driver behavior. For example, the cell for lane keeping assist and "displays appropriate driving when ADAS engaged" would assess if the driver exhibits safe steering and speed control while the system is active. In total, the matrix contains cells spanning 10 ADAS and 6 driving behaviors. This provides a comprehensive evaluation framework to systematically assess drivers' ADAS knowledge and tactical skills during the practical exam. 20 cells have been blacked out as the intersection between the driver behavior and ADAS is not applicable. The assessment notes serve as a guide to examiners when applying the matrix. The matrix is filled in the same was as the current CBR Assessment Matrix, in which a box is marked when the candidate driver does not display the exhibited behavior per the examiner. For example, for the behavior ‘Activates and deactivates successfully (if required)’ is not applicable to ADAS such as Blind Spot Warning (BSW), and Forward Collision Warning (FCW) among others. However, Cruise Control and Adaptive Cruise Control, ADAS whose engagement is dictated by the driver, are systems for which the behavior ‘Activates and deactivates successfully (if required)’ can be evaluated by the examiner. With the initial ADAS Assessment Matrix developed, the next phase involved gathering observational data on ADAS use and evaluation complexities through case studies with driving examiners, putting the matrix through its first stage of validation.

4.3 Case Study I

Key findings from two mock driving exams highlighted the variable applicability of ADAS across different driving scenarios. In low-speed settings, many ADAS features became non-operational, likely due to factors like low speeds or lack of clear road markings. This revealed the nuanced and conditional nature of ADAS functionalities. In high-speed highway driving, the concurrent operation of multiple ADAS introduced complexity in isolating and evaluating individual system performance.

To summarize the key takeaways on ADAS usage and assessment, Table 7 was created. This table outlines the major themes identified regarding ADAS applicability, evaluation challenges, and recommendations from the case study. As shown, ADAS usage and assessment varies considerably based on the driving context. Challenges were encountered in evaluating multiple concurrent ADAS and in using the initial ADAS matrix within time constraints.

Table 7-Findings from Case Study I

ADAS Applicability	Evaluation Challenges	Recommendations
Variable functionality in low vs. high-speed driving	Capturing interactions of concurrent ADAS	Refine ADAS matrix for comprehensive evaluation
Limited operation without clear markings	Time constraints using detailed matrix	Streamline matrix for operational feasibility
Differing applicability across road types/settings	Overlaps with standard CBR assessment	Integrate ADAS matrix into existing tools

Overall, the case study highlighted the need for a refined ADAS assessment framework informed by practical evidence on conditional ADAS usage. Improvements should account for complexity from simultaneous ADAS engagement and better fit real-world exam constraints.

4.4 Matrix Iteration #1

The key findings from the first case study highlighted the need for refining the initial ADAS Assessment Matrix to better address real-world complexities observed during the mock driving exams. This led to the development of the first iteration of the matrix, with modifications made to the structure, content, and specificity based on examiner feedback and observational data. Table 8 shows the first iteration of the ADAS Assessment Matrix

Table 8-First Iteration of the ADAS Assessment Matrix per Results From the First Case Study

Driver Behaviors	*Parking*	*Lane Keeping BSW/LKA*	*Collision Avoidance AEB*	*Speed Limiting*	*Conv-enience ACC*
A. Pre-ride: Checks condition of sensors and cameras ( )					
B. ADAS Familiarity					
Demonstrates knowledge on when to activate/deactivate	( )	( )	( )	( )	( )
Demonstrates knowledge on the functionality of ADAS	( )	( )	( )	( )	( )
C. Vigilance & Environmental Perception					
Attentive to environment and behavior of other road users	( )	( )	( )	( )	( )
D. Operational Control (when ADAS triggered)					
Maintains smooth acceleration and/or braking after ADAS triggered	( )	( )	( )	( )	( )
Demonstrates smooth steering after ADAS triggered	( )	( )	( )	( )	( )
Exhibits competence in managing ACC (acceleration, deceleration, overtaking)	( )	( )	( )	( )	( )
E. Decision Making & Risk Management					
Demonstrates timely response to ADAS alerts	( )	( )	( )	( )	( )
Successfully regains manual control under unusual circumstances	( )	( )	( )	( )	( )
Avoids hinderance to other road users	( )	( )	( )	( )	( )

Structurally, the behaviors were organized into distinct categories (A-E) reflecting meaningful groupings - pre-ride checks, ADAS familiarity, vigilance and environmental perception, operational control, and decision-making and risk management. This categorization introduced logical flow and aided the evaluation process. The ADAS systems were categorized per their functionality and limited to the 6 most relevant ones that exhibit safe use: parking sensors, lane keeping assist, collision avoidance, speed limiting, and convenience features like cruise control/adaptive cruise control. Limiting to these core ADAS functions helped maintain focus on the systems with the highest safety impacts that are most feasible to evaluate given the constraints of the practical driving exam.

In terms of content, nuanced behaviors were added, such as demonstrating knowledge on appropriate activation and deactivation procedures for each ADAS. The emphasis on environmental perception and consideration for other road users underscored the need for drivers to remain vigilant when utilizing ADAS. Exhibiting smooth acceleration, braking, and steering following ADAS status (on/off) highlighted the importance of operational control interactions. The specificity of the criteria was increased to enable more objective assessment. Descriptions of expected actions were added, e.g., timely response to alerts, successful regaining of manual control. Overly vague or overlapping behaviors from the initial matrix were removed, such as “displays desirable driving behavior when using ADAS” which lacked specificity. In summary, the first iteration of the ADAS Assessment Matrix reflected critical changes to the structure, content, and specificity of the behaviors and ADAS functionalities listed. The modifications addressed key considerations raised during the first case study for comprehensively evaluating safe use of ADAS during the practical driving exam. The matrix enhanced the feasibility and effectiveness of assessment, providing a more targeted tool for examiners.

Having presented the key outcomes and first iteration of the ADAS Assessment Matrix, the next section outlines the results obtained from the semi-structured interviews conducted with driving examiners.

4.5 Interviews

Thematic Analysis

Four themes were identified, with a total of 13 sub-themes, shown in Table 9. The four main themes were “Adapting to ADAS”, “Preparing for the Future”, “Examiner Training and Skill Development” and “Policy and Implementation”.

Table 9-Themes and sub-themes derived from thematic analysis of interviews with driving examiners

Adapting to ADAS	Preparing for the Future	Examiner Training and Skill Development	Policy and Implementation
Benefits and Advantages	Driver Assessment	ADAS Education	Financial Implications
Challenges and Limitations	Driver Education	ADAS Skill Development	Stakeholder Dynamics
Youth's Approach to Technology	Role of Examiners	Training Alignment with Testing Changes	Pace of Change
Examiners' Perspective			

Theme 1: Adapting to ADAS

The interviews revealed several insights into the challenges and opportunities presented by the adaptation of ADAS technologies in driver testing and licensing. Table 10 presents the key points.

Table 10-Key Points from Theme 1

Sub-theme	Key Points from Interviews
Benefits and Advantages	ADAS can improve road safety when used properly (Examiner 1, 2, 3) Proper education and training on ADAS is essential (Examiner 1, 2, 3)
Challenges and Limitations	Drivers have limited understanding of ADAS capabilities and limitations (Examiner 1, 2) Overreliance on ADAS can reduce driver engagement (Examiner 2) Evaluating ADAS use is complex due to variability and subjectivity (Examiner 2, 3) Needed ADAS scenarios may not occur in short exams (Examiner 2, 3)
Youth's Approach to Technology	Youth eager to use new in-vehicle tech but may lack understanding of limitations (Examiner 2) Youth may use ADAS casually without safety considerations (Examiner 2) Targeted ADAS education can promote proper use (Examiner 2)
Examiner's Perspective	Examiners recognize need to adapt to vehicle automation (Examiner 1, 2) Maintaining focus on evaluating safe vehicular operation is key (Examiner 3)

	Balance needed between tech skills and core driving competencies (Examiner 1)

"There's a big knowledge gap amongst the car drivers, and it goes for all ages" (Examiner 1)

This quote supports the point that drivers often have limited understanding of ADAS functionalities and limitations.

"When I was in Paris a few years ago going around the perimeter of Paris...One of them was called an SAE 3 level car with systems that could overtake during traffic automatically. I would say it was a bit simple and amateurish." (Examiner 1)

This quote highlights the ongoing adaptation required by examiners as ADAS technologies continue advancing.

In summary, the interviews provided insights into examiner perspectives on opportunities and challenges related to ADAS adaptation. Key points included proper education and training for both drivers and examiners, understanding system capabilities and limitations, maintaining focus on core driving competencies, and effectively evaluating ADAS use in varied testing conditions.

Theme 2: Preparing for the Future

The interviewed examiners emphasized proactive preparation for increased ADAS integration into driver testing and licensing procedures. Table 11 presents the key points.

Table 11-Key Points from Theme 2

Sub-theme	Key Points from Interviews
Driver Assessment	Focus should be on overall vehicular control, not just ADAS use (Examiner 3) Core driving skills remain vital, supplemented by proper ADAS use (Examiner 1, 3) Understanding appropriate ADAS activation/deactivation is key (Examiner 1)
Driver Education	More comprehensive ADAS education needed before licensing testing (Examiner 1, 2) Allows practice with ADAS prior to exam (Examiner 2) Promotes proper use based on system capabilities (Examiner 1)
Role of Examiners	Examiners must adapt to remain relevant in assessing driving competency (Examiner 1) Examiners should take initiative on ADAS rather than lag behind (Examiner 1)

"I think there should be conditions situations where you can make sure. That could be a physical area or a simulator." (Examiner 2)

This quote supports the point that new approaches may be needed to properly evaluate ADAS use given the constraints of practical road exams.

"Well, I think no matter at what moment it is implemented in the driving test, it being implemented will be a victory in itself." (Examiner 3)

This quote highlights the need for proactive integration of ADAS assessment rather than lagging behind vehicle automation.

In summary, preparing for future ADAS integration was seen as crucial by examiners. This involves enhancing driver education, refocusing licensing assessments, and proactive examiner adaptation. A holistic approach assessing knowledge, situational use, and overall vehicular control with ADAS was recommended.

Theme 3: Examiner Training and Skill Development

The interviewed examiners emphasized the importance of enhanced training to evaluate drivers' ADAS use. Table 12 presents the key points.

Table 12-Key Points from Theme 3

Sub-theme	Key Points from Interviews
ADAS Education	Foundational ADAS knowledge lacking in examiner training currently (Examiner 3) Should include ADAS concepts, limitations, algorithms (Examiner 3)
ADAS Skill Development	Hands-on practice needed to understand ADAS capabilities (Examiner 1) Encourage self-driven skill development (Examiner 1)
Training Alignment	Examiner training protocols must keep pace with vehicle automation (Examiner 1, 3) Updates should coincide with changes to ADAS testing (Examiner 1)

"Examiners should have a knowledge base on ADAS concepts like artificial intelligence and algorithms to transition from traditional vehicle operation knowledge to an ICT-focused mindset." (Examiner 3)

This quote supports the need for enhanced ADAS education for examiners on technical concepts and limitations.

In summary, the interviews highlighted the need to enhance examiner training on ADAS concepts and practical skills. Regular training updates, hands-on practice, and self-education were advised to complement any changes to driver assessments.

Theme 4: Policy and Implementation

The examiners discussed several policy and implementation factors that could influence ADAS integration into driver licensing. Table 14 shows these results. Table 13 presents the key points.

Table 13-Key Points from Theme 4

Sub-theme	Key Points from Interviews
Financial Implications	Increased ADAS training/testing carries financial impacts (Examiner 3) Policymakers may resist increased exam costs (Examiner 3)
Stakeholder Dynamics	Coordination needed between licensing agencies, schools, policymakers (Examiner 1, 2) Driving schools may resist costs of change (Examiner 2)
Pace of Change	Sense of urgency to integrate ADAS into assessments (Examiner 1, 2) Balance needed between proactivity and feasibility (Examiner 1)

"I heard about a position paper from CBR which states that it will not be possible to test ADAS within the next years. And I was a bit disappointed to read that as I do not agree." (Examiner 1)

This quote highlights the sense of urgency expressed by some examiners to integrate ADAS assessments.

"Driving schools need to become more professional and coordinated with licensing agencies regarding ADAS training and testing." (Examiner 1)

This quote supports the need for coordination and enhanced training across licensing agencies and driving schools regarding ADAS.

In summary, several policy and implementation factors could influence the integration of ADAS into driver licensing protocols. Considerations around costs, stakeholder coordination, and pace of change were highlighted by examiners.

The next section presents the results of the feedback received from the driving examiner interviews on the first iteration of the ADAS Assessment Matrix.

Feedback on ADAS Assessment Matrix

Based on the key insights gained from the examiner interviews, a second iteration of the ADAS Assessment Matrix was developed to further refine the evaluation criteria and framework.

Table 14-Strengths and Weaknesses/Challenges of the ADAS Matrix per Examiner Feedback

Strengths	Weaknesses/Challenges
Educational value for proper ADAS use (Examiner 3)	Difficulty evaluating ADAS fully in short exams (Examiner 1, 2)
Aligns with current CBR testing principles (Examiner 2)	Measurability and standardization of criteria (Examiner 3)
Covers safety-critical ADAS behaviors (Examiner 3)	Ensuring uniform examiner interpretation (Examiner 2, 3)
Provides structure for holistic evaluation (Examiner 1)	Linking behaviors to pass/fail verdicts (Examiner 3)
	Keeping updated as ADAS evolve (Examiner 1)

Overall, the ADAS Assessment Matrix provides a good foundation for evaluating safety-critical behaviors and knowledge related to ADAS use. However, implementation challenges exist including exam duration constraints, interpretability, measurability, and maintaining relevancy. A combined approach with theory and practical testing is needed. The results indicate that further refinements to the Matrix are required to create standardized, fair assessments amidst rapidly evolving vehicle automation.

To address the insights from the interviews, a refined second iteration of the ADAS matrix was developed with an aim to enhance measurability, ensure applicability amidst constraints, and maintain relevancy despite rapidly evolving technologies. The second iteration of the matrix is presented in the next section.

4.6 Matrix Iteration #2

The key findings from the interviews was the need for refining the ADAS Assessment Matrix to be more in-line with current assessment methods and attuned to the constraints of a driving exam. This

led to the development of the second iteration of the matrix, with modifications made to the structure, content, and measurability based on the examiner feedback. Table 15 shows the second iteration of the ADAS Assessment Matrix.

Table 15-Second Iteration of the ADAS Assessment Matrix per Results From Interviews

Situation & Driver Behavior	Result	Pre-ride check	Knowledge of ADAS		Supervision of Vehicle (when ADAS engaged)			Warnings by ADAS	Take-over Requests	
	Failed	Checks condition of sensors and cameras	Proactive ADAS engagement (on/off)	Responsible use of ADAS (per Rijprocedure)	Monitors operation of in-vehicle systems	Has situational awareness of environment	Does not engage in secondary activities	Responds to warnings and alerts by in-vehicle systems	*Responds to expected take-over requests (system limitations)*	*Responds to un-expected take-over requests (system failures)*
Driving-off										
Driving on Straight & Curvy Road Sections										
Near and at Intersections										
Merging / Exiting										
Overtaking / Lateral Movements										
Behavior at Special Road Sections										
Special Operations										

The structure of the matrix was aligned to the situations outlined in the CBR's *Rijprocedure B* assessment guidelines. This involved framing the matrix around seven driving situations (rows) that candidates commonly encounter during the exam - driving off, driving on road sections, intersections, merging, overtaking, special road sections, and special operations. Aligning the ADAS assessment to these already standardized testing situations enhances its integration within existing exam protocols. In addition, behaviors were also linked to pass/fail verdicts.

The driver behaviors to be tested against the situations were updated from ADAS specific behaviors to generalizable driver competencies fundamental to safe ADAS use. Nine core competencies (columns) emerged - checking sensors, proactive ADAS use, responsible use per protocols, monitoring systems, situational awareness, hand/eye/feet coordination, avoiding distractions, responding to warnings, and takeover requests. Focusing on universal competencies provides flexibility to assess drivers regardless of specific ADAS present.

Interviews with examiners revealed the need for clear interpretation of the driver behavior to be assessed. This will allow for uniform interpretation across all examiners. Vague behaviors that are not able to be measured qualitatively, were updated to distinct behaviors that allowed examiners to have a more accurate notion of whether the drivers exhibit said behavior. For example, demonstrating knowledge of activation/deactivation of ADAS and it's functionality was removed, and replaced with 'Proactive ADAS engagement (on/off)' and 'Responsible use of ADAS (per Rijprocedure)' respectively.

In summary, the second iteration of the matrix demonstrates critical changes to align with standardized testing protocols, focus on generalizable competencies, and provide examiners with clear, measurable behaviors for uniform assess drivers' safe use of ADAS. Having refined the matrix through insights from examiner interviews, the next phase involved conducting a case study to test the matrix's applicability in a real-world testing scenario with an examiner and driver.

4.7 Case Study II

The participants in this second case study were an examiner and a driver, both replicating the settings of a practical driving exam. The examiner was a middle-aged Dutch male with two decades of experience conducting driving tests. He received training on ADAS in 2015. He conducted driving examinations in the province of Gelderland in the Netherlands, administering approximately 100 driving tests per year. The participant was a young adult Dutch male driver who drives between one to five

thousand kilometers annually and passed the driving exam in 2016. The participant drives a car equipped with adaptive cruise control (ACC) and indicated having a basic understanding of the functionality and limitations of ACC systems specifically. However, he reported having a good understanding of the functionality and limitations of ADAS

First, the interpretation of the terms by the examiner and driver is presented. This is followed by the expert's assessment of the driver's performance relating to the safe use of ADAS. Finally, the self-evaluation capabilities of the matrix are presented, with it being an important aspect of driver education.

1. Interpretation of fields in ADAS Matrix by examiner and driver

Table 16-Examiner's Ratings on Terms in ADAS Matrix applied in Case Study 2

Category	Aspect	Interpretability
Pre-ride check	Checks condition of sensors and cameras	Easy
Knowledge of ADAS	Proactive ADAS engagement (on/off)	Easy
	Demonstrates functional knowledge of ADAS (per Rijprocedure)	Easy
Supervision of Vehicle (when ADAS engaged)	Monitors operation of in-vehicle systems	Easy
	"Has situational awareness of environment (other road users and objects)"	Very easy
	Does not engage in secondary activities while driving	Very easy
Warnings by ADAS	Responds to warnings and alerts by in-vehicle systems	Easy
Take-over Requests by ADAS	Responds to expected take-over requests (e.g., limits of ODD)	Very easy
	Responds to unexpected take-over requests (e.g., system failures)	Very easy

Table 17-Driver's Ratings on Terms in ADAS Matrix applied in Case Study 2

Category	Aspect	Interpretability
Pre-ride check	Checks condition of sensors and cameras	Difficult
Knowledge of ADAS	Proactive ADAS engagement (on/off)	Moderate
	Demonstrates functional knowledge of ADAS (per Rijprocedure)	Easy
Supervision of Vehicle (when ADAS engaged)	Monitors operation of in-vehicle systems	Difficult
	"Has situational awareness of environment (other road users and objects)"	Very easy
	Does not engage in secondary activities while driving	Very easy
Warnings by ADAS	Responds to warnings and alerts by in-vehicle systems	Moderate

Take-over Requests by ADAS	Responds to expected take-over requests (e.g., limits of ODD)	Moderate
	Responds to unexpected take-over requests (e.g., system failures)	Easy

2. Expert Assessment of Driving Performance

Table 18-Examiner's Ratings on Driver Performance in Case Study 2 (Average of two Runs)

Category	Aspect	Driver Performance
Pre-ride check	Checks condition of sensors and cameras	Adequate performance
Knowledge of ADAS	Proactive ADAS engagement (on/off)	Basic but incomplete understanding
	Demonstrates functional knowledge of ADAS (per Rijprocedure)	Basic competency
Supervision of Vehicle (when ADAS engaged)	Monitors operation of in-vehicle systems	Good performance
	"Has situational awareness of environment (other road users and objects)"	Moderately adequate responsiveness
	Does not engage in secondary activities while driving	Basic proficiency
Warnings by ADAS	Responds to warnings and alerts by in-vehicle systems	Slight lack of readiness
Take-over Requests by ADAS	Responds to expected take-over requests (e.g., limits of ODD)	Adequate performance
	Responds to unexpected take-over requests (e.g., system failures)	Basic but incomplete understanding

3. Self-evaluation of Driving Performance

Table 19-Driver's Ratings on Own Performance in Case Study 2 (Average of Two Runs)

Category	Aspect	Self-performance
Pre-ride check	Checks condition of sensors and cameras	Good performance
Knowledge of ADAS	Proactive ADAS engagement (on/off)	Good performance
	Demonstrates functional knowledge of ADAS (per Rijprocedure)	Good performance
Supervision of Vehicle (when ADAS engaged)	Monitors operation of in-vehicle systems	Very good ability
	"Has situational awareness of environment (other road users and objects)"	High confidence in responsiveness
	Does not engage in secondary activities while driving	High competency
Warnings by ADAS	Responds to warnings and alerts by in-vehicle systems	High competency
Take-over Requests by ADAS	Responds to expected take-over requests (e.g., limits of ODD)	Good performance
	Responds to unexpected take-over requests (e.g., system failures)	Good performance

4.8 Final ADAS Assessment Matrix

Table 20-Final ADAS Assessment Matrix

Situation & Driver Behavior	Result	Pre-ride check	Knowledge of ADAS		Supervision of Vehicle (when ADAS engaged)		Warnings by ADAS	Take-over Requests
	Failed	Checks condition of sensors and cameras	Proactive ADAS engagement (on/off)	Responsible use of ADAS (per Rijprocedure)	Monitors operation of in-vehicle systems	Has situational awareness of environment	Responds to warnings and alerts by in-vehicle systems	*Responds to expected take-over requests (system limitations)*
Driving-off								
Driving on Straight & Curvy Road Sections								
Near and at Intersections								
Merging / Exiting								
Overtaking / Lateral Movements								
Behavior at Special Road Sections								
Special Operations								

The second case study provided valuable real-world insights to refine the ADAS Assessment Matrix and optimize its functionality for a driving exam. Several key modifications were implemented in the final matrix based on the observational data and participant feedback gathered. Most significantly, the criteria of "Does not engage in secondary activities while driving" was removed after it was observed that opportunities for distraction are minimal during the controlled structure of driving exams. Since drivers are unlikely to engage in secondary activities in driving exams, assessing this behavior was

considered non-critical. The criteria "Responds to unexpected take-over requests" was also eliminated based on examiner feedback regarding the difficulty of safely and realistically evaluating this skill. To prioritize feasibility, this criteria was also deemed impractical for standardized testing conditions.

Overall, the second case study affirmed the ADAS Assessment Matrix as a valid tool for evaluating driver ADAS competency, while also revealing key opportunities to tailor the matrix to the practical needs of the driving exam setting. The resulting modifications aimed to enhance the matrix's feasibility, clarity, and comprehensiveness as an assessment tool for examiners. Further iterative refinements can serve to continuously improve the matrix as ADAS technologies progress.

In summary, the key findings from the case studies and examiner interviews enabled the iterative development of an ADAS Assessment Matrix tailored to evaluating safe ADAS use during practical driving exams. The conditional operation of ADAS across diverse scenarios, complexity of concurrent system engagement, time constraints for comprehensive evaluation, and need for integration with existing protocols emerged as critical considerations for developing a pragmatic yet effective assessment tool. Building on these results, the next Discussion chapter will interpret the significance of these findings, including important implications for shaping ADAS evaluation policies and procedures to enhance road safety.

Chapter 5 – Discussion

The results presented in the previous chapter addressed the research question guiding this study by presenting an ADAS Assessment Matrix that can assist driving examiners in effectively evaluating the safe use of ADAS by candidates during a practical driving exam. An initial ADAS assessment matrix, informed by a review of literature, underwent three iterative refinements based on real-world case studies and examiner feedback through interviews. This iterative process allowed for continuous improvements to the matrix to ensure it would be an effective evaluation tool for examiners. Key findings from the case-studies included the conditionality of ADAS operation across driving scenarios, complexity of concurrent operation of ADAS, need to seamlessly integrate ADAS assessment into existing tools, and the importance examiner training.

The discussions chapter will now interpret these findings, consider theoretical and practical implications, and acknowledge limitations. Section 5.1 discusses the results of the interview, followed by Section 5.2 which discusses the results of the case studies. Section 5.3 discusses the ADAS Assessment Matrix. Lastly, Section 5.4 discusses the limitations of the research.

5.1 Interpretation of Interviews

Theme 1: Adapting to ADAS

The interviews revealed several insights into examiners' perspectives on the opportunities and challenges of adapting to increased vehicle automation through ADAS. A key finding was examiners' recognition of the safety benefits of ADAS if used properly, such as reduced crash rates for specific incident types (Cicchino, 2017, 2018a, 2018b). However, multiple examiners also voiced concerns about improper reliance on ADAS leading to driver disengagement and lack of situational awareness. This aligns with studies showing over trust in automation can reduce driver vigilance and hazard mitigation actions (Banks & Stanton, 2019).

Additionally, examiners emphasized the need for comprehensive ADAS training for both aspirant drivers and themselves as assessors. They stressed that targeted education on actual ADAS limitations and appropriate usage is essential, especially for youth. This aligns with recommendations from researchers for improved training programs that accurately convey system capabilities and shape proper mental models (Casner & Hutchins, 2019; Noble et al., 2019). Examiners also acknowledged their own knowledge gaps regarding ADAS concepts, highlighting the need for hands-on skill building to become proficient at evaluations. This supports findings that examiners require extensive familiarity with ADAS technologies to effectively test drivers (Heikoop et al., 2020).

Overall, the theme of adapting to ADAS underscores examiners' balanced perspective, recognizing potential benefits but also the risks from improper adaptation among themselves and the driving public. Their insights align with and expand on evidence regarding opportunities to improve road safety through ADAS, while emphasizing the pivotal role of user education and training. Targeted, experience-based ADAS

Theme 2: Preparing for the Future

The interviews highlighted examiners' emphasis on proactive preparation for increased ADAS integration into driver testing and licensing. A key perspective was that core driving skills must remain the focus of assessments, supplemented by proper ADAS activation knowledge. This aligns with the goal of evaluating overall vehicular control competency rather than just interaction with (Heikoop et al., 2020). Examiners stressed that while ADAS usage should be assessed, traditional operational and tactical skills like steering and hazard perception remain vital.

Additionally, examiners advised that more comprehensive ADAS education is needed prior to testing. They felt this would allow candidates to gain experience with ADAS in training, leading to safer usage during exams. Researchers echo the need to incorporate ADAS more extensively in pre-test curriculums to promote proper mental models (Noble et al., 2019). Examiners also emphasized their

own responsibility to proactively adapt to remain relevant assessors amidst vehicle automation. This aligns with calls for examiners to take the initiative on integrating technology rather than lag behind (Heikoop et al., 2020).

In summary, the theme of proactive preparation underscores examiners' forward-looking mindset to get ahead of the curve on ADAS. Their insights align with evidence on refocusing assessments on total vehicular control while integrating ADAS exposure in pre-test training phases. A dual emphasis on evolving core competencies while actively adapting emerges as key to optimally prepare for increasingly automated vehicles instruction emerges as a priority for enabling safe adaptation.

Theme 3: Examiner Training and Skill Development

The interviews highlighted examiners' perspectives on the importance of enhanced ADAS training for themselves as assessors. A key finding was their acknowledgment of foundational ADAS knowledge gaps in current examiner training programs. They emphasized the need for education on technical concepts like ADAS algorithms and limitations to align with vehicle automation trends. This supports recommendations for comprehensive ADAS instruction for examiners on system capabilities (Heikoop et al., 2020; Tsapi, 2020).

Examiners also advised that hands-on skill development is crucial for understanding ADAS dynamics. They felt self-driven practice is key to build proficiency. This aligns with evidence that experience-based learning is essential for examiners to grasp ADAS behaviors (Heikoop et al., 2020). Finally, examiners noted training protocols must keep pace with changes in ADAS testing. They felt updates should coincide with modifications to driver assessments to maintain relevance. Researchers agree that frequent examiner training updates are critical for reliable ADAS evaluations (Tsapi, 2020; Vlakveld & Wesseling, 2018).

In summary, the theme of examiner training indicates that instructing assessors on ADAS is considered an urgent priority. Examiners' insights align with calls for expanded ADAS education, hands-

on skill practice, and regular training updates to enable examiners to keep pace with vehicle automation. Developing ADAS assessment competence through multifaceted training emerges as vital for fair, standardized tests

Theme 4: Policy and Implementation

The interviews revealed examiners' perspectives on policy and implementation factors influencing ADAS integration in driver licensing. A key consideration discussed was financial implications of increased ADAS training and testing requirements. Examiners noted expanded programs may face resistance due to increased costs for licensing agencies. This aligns with literature indicating resource requirements present a barrier for comprehensive ADAS integration (Vlakveld, 2019).

Examiners also emphasized the need for coordination across stakeholders like schools, agencies, and policymakers regarding ADAS programs. They noted schools may oppose costs of curriculum changes. Researchers agree that synchronized efforts between key groups are essential for effective ADAS education and testing (Polders et al., 2017; Roemer, 2021). Finally, most examiners expressed urgency for integration despite feasibility constraints, though balance was advised. This underscores the delicate balance between proactive adaptation and practical limitations mentioned across studies (Heikoop et al., 2020; Vlakveld & Wesseling, 2018) .

In summary, the theme of policy and implementation considerations reflects examiners' nuanced perspectives on the real-world factors influencing ADAS integration. Their insights echo evidence on overcoming costs, enhancing stakeholder partnerships, and maintaining realistic timelines in shaping impactful ADAS policies and procedures. A collaborative, adaptable, forward-thinking approach emerges as key.

With the interpretation of the themes identified during interviews with the driving examiners, the next section will discuss the results from the two case studies.

5.2 Interpretation of Case Studies

The two case studies highlighted important findings regarding the real-world complexities of evaluating safe use of ADAS during practical licensing exams. These insights are directly relevant to the research objective of equipping driving examiners with a method to evaluate the safe use of ADAS.

A key observation was made regarding the conditional functionality of ADAS across diverse scenarios. For instance, it was observed that many features became non-operational at low speeds or on roads lacking clear markings, likely due to factors that limit sensing capabilities. This was seen to complicate assessment, as ADAS may not be consistently available across varying exam conditions and routes. Additionally, difficulty was encountered in isolating and evaluating individual systems when concurrent operation of multiple ADAS was present. This underscored the need for holistic assessment focused on total vehicular control competency supplemented by ADAS proficiency.

The tightly controlled structure and time limitations of exams also posed challenges that were observed in thoroughly evaluating ADAS knowledge and skills. For instance, it was observed that opportunities for distracted behavior are minimal in exams, suggesting this may not need emphasis in ADAS assessments. The difficulty evaluating certain skills like responding to ADAS failures also indicates prioritizing feasibility.

These findings were seen to have important implications for developing practical ADAS assessment tools. The observed variability in ADAS availability highlighted the need to design adaptable evaluation methods rather than relying on specific systems being present. The complexity encountered with concurrent ADAS engagement emphasized measuring holistic overarching competencies like vigilance and situational awareness. The exam constraints highlighted the necessity of focused, standardized protocols that align with current procedures and priorities.

Overall, the empirical insights from the case studies were invaluable in tailoring the ADAS Assessment Matrix toward an effective and pragmatic tool for examiners. The findings revealed key

factors around conditional ADAS functionality, emphasis on holistic competencies, and integration with existing protocols that helped optimize the matrix. Iterative refinement based on accumulating practical evidence was used to further enhance feasibility and safety evaluation.

5.3 ADAS Assessment Matrix

The development and validation of the ADAS Assessment Matrix provided insights into creating an effective yet feasible tool for examiners to evaluate safe use of ADAS by drivers during the practical driving exam. The iterative process involved an initial literature-informed draft, modifications based on case study observations, refinement per examiner interviews, and final adjustments after field testing. This multi-phase approach allowed for progressive enhancements to optimize the matrix for real-world implementation.

The case studies and interviews highlighted key criteria and constraints to integrate into the matrix. For instance, emphasis on general ADAS competencies rather than system-specific skills provided flexibility for diverse technologies. Time limitations necessitated focus on core knowledge and behaviors most vital for safety. Insights also shaped structural alignments with standardized testing protocols to enable integration. However, challenges remained in evaluating skills like responding to ADAS failures, indicating further refinements may be needed.

Overall, the research underscored that developing robust yet practical ADAS assessment methods requires grounding in literature and empirical evidence. The matrix provides a starting point that can be built upon through expanded trials and continued evolution. While insights may not fully generalize across regions, the iterative approach illustrates integrating essential competencies into licensing protocols as automation advances. With further refinement, the ADAS Assessment Matrix can enable reliable measurement of safety-critical ADAS knowledge and skills by driving examiners worldwide.

5.4 Limitations

Several limitations of this research were identified that should be considered when interpreting the findings. The qualitative methods employed introduced subjectivity that was inherent in the data collection and analysis processes. Mitigation strategies such as utilizing multiple analysts and soliciting participant validation could have strengthened objectivity (Creswell & Creswell, 2017). The narrow focus solely on examiners in the Netherlands limited generalizability and applicability to other geographic regions that have different licensing systems, vehicle fleets, and road environments. The small sample of 5 examiner participants restricted representation of the overall population of examiners. Additionally, it was acknowledged that volunteer participation introduced self-selection bias, as those who were motivated to participate likely differed on important factors from the overall population.

The evolution of ADAS technologies meant that the specific systems studied provided just a snapshot in time that will become outdated without continual updating, limiting long-term relevance of the findings. The constrained duration of the mock driving exams provided few chances to comprehensively evaluate the full range of ADAS knowledge and skills. Reliance on examiner discretion and qualitative judgments rather than quantified performance measurement made achieving consistent, reliable assessment of candidates' skills scientifically challenging. Ethical and practical feasibility concerns prevented studying real novice drivers, limiting generalizability of findings from the mock exams conducted with experienced driver participants. Variability in the ADAS technologies present across the vehicles used in the case studies introduced inconsistencies into the assessment methods under investigation. Policy constraints largely restricted recommendations to incremental near-term improvements rather than radical systemic changes that may have been optimal from a scientific perspective. Finally, the inherent subjectivity involved in practical performance tests means variability in assessment judgments between examiners likely persists despite efforts to promote standardization and objectivity.

To conclude, while this research provided valuable insights, it's important to note its limitations from a scientific standpoint, so the findings are not overstated. The sample size was small and from a limited geographic area. The observation period was short. There were no standardized quantitative measurements of performance. To make the research more objective, valid, reliable and generalizable, future studies could benefit from larger sample sizes, participants from diverse geographic locations, longer observation periods, and incorporating quantified performance measurements.

In summary, the discussion of the results obtained through the case studies and examiner interviews revealed important insights into the considerations for developing an effective yet feasible ADAS assessment tool for driving examiners. Key points included the need to accommodate conditional ADAS operation across diverse driving contexts, focus holistic evaluation on overarching competencies, pragmatically integrate assessments within time-limited exam structures, and continuously update protocols to keep pace with evolving technologies. The study underscores that integrating essential ADAS competence checks into existing licensing evaluations through a collaborative, iterative approach can enable the standardization of safety-critical assessments as vehicle automation progresses. Building on these discussion outcomes, the following Conclusion chapter will synthesize the key findings and recommendations that emerged from this research regarding the effective incorporation of ADAS use assessments into practical driving examinations.

Chapter 6 – Conclusion

6.1 Answers to the research question

The objective of this research was to develop a novel Assessment Matrix to assist driving examiners in evaluating candidates' safe use of ADAS in the practical driving exam in the Netherlands. By conducting a comprehensive analysis of the factors impacting the safe use of ADAS, an Assessment Matrix was developed. The matrix was iterated through two case studies and a set of three interviews, with driving examiners as the main participants. This research aimed to answer the following main research question to achieve the research objectives, "**How can driving examiners effectively evaluate safe use of Advanced Driver Assistance Systems by a candidate during a practical driving exam?**". To answer this main research question, four sub-questions were developed. In the following section, the different research sub-questions are presented and answered.

1. **What are the current gaps in evaluating safe ADAS use during a driving exam?**

The research revealed several key gaps in the current approach to evaluating safe use of ADAS during practical driving exams. Firstly, literature and interviews with examiners highlighted a predominant focus on assessing traditional manual driving skills like vehicle control, observations, and hazard response (CBR, 2023b; Vlakveld & Wesseling, 2018). However, as discussed in Section 4.2 from Chapter 2, ADAS has transformed required competencies toward supervision, monitoring, and dynamic intervention (Banks & Stanton, 2019; Spulber, 2016). This misalignment demonstrates outdated testing priorities that fail to capture modern ADAS-related abilities.

Secondly, examiners unanimously acknowledged that the use of ADAS is currently not formally evaluated in a structured, comprehensive way during exams in line with previous research from Heikoop et al. (2020) and Vlakveld and Wesseling (2018). Only recently have initial guidelines been proposed, although they still require extensive development into assessment protocols (CBR, 2023b). This points to

a lack of well-defined, standardized ADAS evaluation methods representing a substantial gap in evaluating safe use of ADAS in practical driving exams.

Third, interviews highlighted the limitations of examiners' own foundational ADAS knowledge, having received minimal formal training on concepts and system dynamics (Examiner 1, Examiner 3). Equipping examiners to effectively assess safe use of ADAS requires addressing these skills gaps first. Finally, case studies revealed difficulties evaluating ADAS thoroughly within the time-limited, variable conditions of on-road exams (Section 4.3). Constraints on opportunities to demonstrate and evaluate ADAS competence poses barriers.

In summary, gaps exist in ADAS assessment priorities, protocols, examiner readiness, and practical feasibility that demonstrate a need for updated evaluation methods. Addressing these limitations will enable integration of safety-critical ADAS competence checks into evolving practical driving exams.

2. Which ADAS-related driver behaviors are essential for driving examiners to evaluate for safe ADAS use?

Research identified several core competencies and tactical skills essential for safe ADAS operation. Thoroughly checking the condition of sensors and cameras before driving is critical for ensuring ADAS functionality (CBR, 2023b). Drivers must also demonstrate knowledge of proper procedures for activating and deactivating specific ADAS in varying conditions (Spulber, 2016). Situational awareness of the surrounding environment should be maintained while ADAS are active to enable proactive hazard identification (Examiner interviews). Constant monitoring of ADAS operation provides attentiveness to intervene if needed (Banks & Stanton, 2019). Timely response to system alerts and warnings exhibits readiness to takeover if prompted (ADAS Assessment Matrix). Smooth vehicular control inputs following ADAS triggers demonstrates retained operational command (ADAS Assessment Matrix). The ability to successfully regain manual control when requested, both for expected and unexpected takeovers, is

pivotal for coordination (Spulber, 2016). Drivers should avoid secondary distractions that compromise supervision when using ADAS (Casner & Hutchins, 2019). Responsible ADAS usage requires comprehending system limitations across conditions to exercise discretion (Examiner 3 interview). Overall, mastering this range of knowledge-based, operational and tactical competencies is essential for safe ADAS adoption and effective human-machine coordination as vehicle automation evolves.

3. How can observing ADAS use in real-world driving situations inform effective evaluation methods for examiners?

The case studies revealed variability in ADAS functionality across diverse driving scenarios, with some features becoming non-operational at low speeds or on roads lacking markings (Section 4.3). This indicates evaluations should accommodate fluctuations in system performance across conditions. Concurrent operation of multiple ADAS introduced difficulty isolating individual feature assessments (Section 4.3). This highlights the need to focus evaluation on overall competent ADAS use rather than specific technologies.

Observing driver actions revealed key competencies for assessment like maintaining situational awareness, monitoring systems, and smooth takeover control (Section 4.7-4.8). However, thorough evaluation of all ADAS knowledge and skills was constrained within time-limited exams (Section 4.3). This signals a need to streamline assessment protocols. Overlaps with standard testing criteria suggested integrating ADAS checks into existing tools efficiently versus standalone evaluations (Section 4.3).

Overall, real-world observations provided critical insights on key ADAS competencies for evaluation while revealing feasibility constraints posed by exam duration and structure. These lessons can shape pragmatic assessment tools that effectively capture core ADAS proficiency within operational limits. The ADAS Assessment Matrix developed through this empirical approach balances comprehensiveness and practicality (Section 4.8). In summary, grounded observation is invaluable for guiding the creation of standardized, efficient ADAS evaluation aligned with complex real-world contexts.

4. What recommendations can be made based on the findings to effectively incorporate ADAS use evaluation into the driving exam?

Recommendations for effectively incorporating ADAS evaluation in driving exams are as follows:

- Integrate ADAS checks into existing practical exam tools rather than standalone assessments to enhance efficiency and minimize redundancy (Section 4.3).
- Focus evaluations holistically on overall competent ADAS use rather than isolating proficiency with specific features due to interplay of multiple systems (Section 4.3).
- Prioritize assessing core competencies like situational awareness, system monitoring, and takeover readiness that findings revealed as essential for safety (Section 4.7-4.8).
- Streamline assessment protocols and criteria to fit within constrained exam duration and structure (Section 4.3).
- Implement standardized ADAS training and testing to align instructor materials, promote uniformity in grading, and improve candidate learning (Examiner interviews).
- Provide formalized ADAS education programs, beyond reliance on operation manuals and dealerships, to address knowledge gaps among the public (Literature review).
- Ensure driving examiners receive immersive, hands-on ADAS training to improve technology fluency and evaluation skills (Examiner interviews).
- Consider use of driving simulators to safely evaluate ADAS competency in hazardous scenarios difficult to recreate on-road (Examiner interviews).
- Continuously update ADAS training and assessment practices through collaborative research between educators, industry partners and policymakers.

In summary, recommendations encompass the pragmatic integration of ADAS checks into existing exams and emphasizing the assessment of core safety-critical competencies. Additionally, there is a need

to close driver knowledge gaps through formal training, enhance examiner qualifications, and maintain collaborative efforts to keep evaluations aligned with advancements in vehicle automation.

6.2 Recommendations for future research

This research revealed key insights into developing effective ADAS assessment methods, but also highlighted avenues for continued investigation. Larger samples of examiners and drivers would enhance the applicability and provide data to refine evaluation protocols. Studies directly observing ADAS use by novice drivers, using instrumented vehicles and naturalistic methods, could reveal additional safety-critical competencies for assessment. Collaborating with automakers to implement testing using authentic vehicle automation capabilities would enhance real-world accuracy. Research into augmenting examiner training with immersive scenarios in a simulator could inform improvements.

Investigating knowledge retention from standardized ADAS education would help optimize instructional approaches. Broader partnerships with licensing agencies globally would facilitate sharing of best practices to harmonize ADAS testing standards worldwide. And continuously updating research through rapid-cycle prototyping would ensure integration of evolving technologies into driver training and evaluation.

In summary, this thesis establishes a critical evidence-based groundwork for evaluating the safe use of ADAS. Future progress will benefit from diverse research collaborations and technological innovation.

References

Alonso Raposo, M., Grosso, M., Després, J., Macias, E., Galassi, M. C., krasenbrink, a., Krause, J., levati, l., Mourtzouchou, A., Saveyn, B., Thiel, C., & Ciuffo, B. (2018). *An analysis of possible socio-economic effects of a Cooperative, Connected and Automated Mobility (CCAM) in Europe*. https://doi.org/10.2760/777

Arbib, J., & Seba, T. (2017). Rethinking transportation 2020–2030: The disruption of transportation and the collapse of the internal combustion vehicle and oil industries. A RethinkX sector disruption Report, May 2017. RethinkZ, 77 pp. In.

Atkinson, K. M., Koenka, A. C., Sanchez, C. E., Moshontz, H., & Cooper, H. (2015). Reporting standards for literature searches and report inclusion criteria: making research syntheses more transparent and easy to replicate. *Research synthesis methods*, *6*(1), 87-95.

Bainbridge, L. (1983). Ironies of automation. *Automatica*, *19*(6), 775-779. https://doi.org/https://doi.org/10.1016/0005-1098(83)90046-8

Banks, V. A., & Stanton, N. A. (2019). Analysis of driver roles: modelling the changing role of the driver in automated driving systems using EAST. *Theoretical Issues in Ergonomics Science*, *20*(3), 284-300. https://doi.org/10.1080/1463922X.2017.1305465

Baughan, C. J., Sexton, B. F., Maycock, G. A., Simpson, H., Chinn, L., & Quijmby, A. (2005). Novice driver safety and the British practical driving test.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Brinkmann, S., & Kvale, S. (2015). *Interviews: Learning the craft of qualitative research interviewing*. Sage publications.

Casner, S. M., & Hutchins, E. L. (2019). What Do We Tell the Drivers? Toward Minimum Driver Training Standards for Partially Automated Cars. *Journal of Cognitive Engineering and Decision Making*, *13*(2), 55-66. https://doi.org/10.1177/1555343419830901

CBR. (2015). Assistance Systems Allowed During Driving Examination; . https://www.cbr.nl/nl/over-het-cbr/over/laatste-nieuws/nieuws/ondersteunende-systemen-toegestaan-in-rijexamen.htm

CBR. (2023a). *Examinatorenopleiding*. https://werkenbijcbr.nl/examinatorenopleiding

CBR. (2023b). *Rijprocedure B*. Rijswijk Retrieved from https://www.cbr.nl/nl/service/nl/artikel/rijprocedure-b-2.htm

Cicchino, J. B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention*, *99*, 142-152. https://doi.org/https://doi.org/10.1016/j.aap.2016.11.009

Cicchino, J. B. (2018a). Effects of blind spot monitoring systems on police-reported lane-change crashes. *Traffic Injury Prevention*, *19*(6), 615-622. https://doi.org/10.1080/15389588.2018.1476973

Cicchino, J. B. (2018b). Effects of lane departure warning on police-reported crash rates. *Journal of Safety Research*, *66*, 61-70. https://doi.org/https://doi.org/10.1016/j.jsr.2018.05.006

Clements, L., & Kockelman, K. (2017). Economic Effects of Automated Vehicles. *Transportation Research Record: Journal of the Transportation Research Board*, *2606*, 106-114. https://doi.org/10.3141/2606-14

Cohn, J., Ezike, R., Martin, J., Donkor, K., Ridgway, M., & Balding, M. (2019). Examining the Equity Impacts of Autonomous Vehicles: A Travel Demand Model Approach. *Transportation Research Record: Journal of the Transportation Research Board*, *2673*, 036119811983697. https://doi.org/10.1177/0361198119836971

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Crinson, L. F., & Grayson, G. B. (2005). Profile of the British learner driver. *Traffic and transport psychology, theory and application*, 157-170.

De Vos, B., Cuenen, A., Ross, V., Dirix, H., Brijs, K., & Brijs, T. (2023). The Effectiveness of an Intelligent Speed Assistance System with Real-Time Speeding Interventions for Truck Drivers: A Belgian Simulator Study. *Sustainability*, *15*(6), 5226. https://www.mdpi.com/2071-1050/15/6/5226

de Winter, J. C. F. (2013). Predicting self-reported violations among novice license drivers using pre-license simulator measures. *Accident Analysis & Prevention*, *52*, 71-79. https://doi.org/https://doi.org/10.1016/j.aap.2012.12.018

Dijsselbloem, J. R. V. A. V. A., M.B.A.; , & Zouridis, S. (2019). *Who is in control? Road safety and automation in road traffic*.

Driessen, T., Picco, A., Dodou, D., de Waard, D., & de Winter, J. (2021). Driving examiners' views on data-driven assessment of test candidates: An interview study. *Transportation research part F: traffic psychology and behaviour*, *83*, 60-79. https://doi.org/https://doi.org/10.1016/j.trf.2021.09.021

Ebnali, M., Hulme, K., Ebnali-Heidari, A., & Mazloumi, A. (2019). How does training effect users' attitudes and skills needed for highly automated driving? *Transportation research part F: traffic psychology and behaviour*, *66*, 184-195. https://doi.org/https://doi.org/10.1016/j.trf.2019.09.001

Edwards, J., Perrone, A., & Doyle, P. R. (2020). *Transparency in Language Generation: Levels of Automation* Proceedings of the 2nd Conference on Conversational User Interfaces, Bilbao, Spain. https://doi.org/10.1145/3405755.3406136

Emory, K., Douma, F., & Cao, J. (2022). Autonomous vehicle policies with equity implications: Patterns and gaps. *Transportation Research Interdisciplinary Perspectives*, *13*, 100521. https://doi.org/https://doi.org/10.1016/j.trip.2021.100521

Enayati, J., Jonnalagadda, Y., & Asef, P. (2022, 17-17 Dec. 2022). A Novel Triple Radar Arrangement for Level 2 ADAS Detection System in Autonomous Vehicles. 2022 IEEE 10th Conference on Systems, Process & Control (ICSPC),

Directive 2006/126/EC of the European Parliament and of the Council of 20 December 2006 on driving licences, (2006). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32006L0126&from=EN

Regulation (EU) 2019/2144, (2019). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R2144&from=EN

Directive of the European Parliament and of the Council on driving licences, amending Directive (EU) 2022/2561 of the European Parliament and of the Council, Regulation (EU) 2018/1724 of the European Parliament and of the Council and repealing Directive 2006/126/EC of the European Parliament and of the Council and Commission Regulation (EU) No 383/2012 (2023). https://transport.ec.europa.eu/system/files/2023-03/COM_2023_127.pdf

Galvani, M. (2019). History and future of driver assistance. *IEEE Instrumentation & Measurement Magazine*, *22*(1), 11-16.

Goodall, N. J. (2016). Can you program ethics into a self-driving car? *IEEE Spectrum*, *53*(6), 28-58. https://doi.org/10.1109/MSPEC.2016.7473149

Goodin, C., Carruth, D., Doude, M., & Hudson, C. (2019). Predicting the Influence of Rain on LIDAR in ADAS. *Electronics*, *8*(1), 89. https://www.mdpi.com/2079-9292/8/1/89

Government, D. (2013). *Regulation requirements practical exams driving license categories B and E at B (Regulation requirements practical exams driving license categories B and E at B)*. https://wetten.overheid.nl/BWBR0015600/2013-12-31

Gowda, D. V., & Ramachandra, A. (2018). IMPORTANCE OF NON-LINEAR CONTROLLER IN IMPLEMENTING ANTI-LOCK BRAKING SYSTEM-A TECHNICAL REVIEW. *International Journal of Advanced Research in Computer Science*, *9*(2).

Groover, M. P. (2023). Automation. In: Britannica

Hale, A. R., Stoop, J. A., & Hommels, J. (1990). Human error models as predictors of accident scenarios for designers in road transport systems. *Ergonomics*, *33*. https://doi.org/10.1080/00140139008925339

Heikoop, D., Calvert, S., Mecacci, G., & Hagenzieker, M. (2020). *A practitioner's View of Driver Training for automated driving From Driving Examiners: A Focus group Discussion*. https://doi.org/10.1109/FISTS46898.2020.9264869

Heikoop, D. D., de Winter, J. C. F., van Arem, B., & Stanton, N. A. (2016). Psychological constructs in driving automation: a consensus model and critical comment on construct proliferation. *Theoretical Issues in Ergonomics Science*, *17*(3), 284-303. https://doi.org/10.1080/1463922X.2015.1101507

Heikoop, D. D., Hagenzieker, M., Mecacci, G., Calvert, S., Santoni De Sio, F., & van Arem, B. (2019). Human behaviour with automated driving systems: a quantitative framework for meaningful human control. *Theoretical Issues in Ergonomics Science*, *20*(6), 711-730. https://doi.org/10.1080/1463922X.2019.1574931

Helman, S, Vlakveld, W., Fildes, B., Oxley, J., Fernández-Medina, K., & Weekley, J. (2017). *Study on driver training, testing and medical fitness; Final report*.

Himmelreich, J. (2018). Never Mind the Trolley: The Ethics of Autonomous Vehicles in Mundane Situations. *Ethical Theory and Moral Practice*, *21*(3), 669-684. https://doi.org/10.1007/s10677-018-9896-4

Hoc, J.-M., Young, M. S., & Blosseville, J.-M. (2009). Cooperation between drivers and automation: implications for safety. *Theoretical Issues in Ergonomics Science*, *10*(2), 135-160. https://doi.org/10.1080/14639220802368856

Jacob, S. A., & Furgerson, S. P. (2012). Writing interview protocols and conducting interviews: Tips for students new to the field of qualitative research. *Qualitative report*, *17*, 6.

Johnson, C., & Walker, J. (2016). Peak car ownership: the market opportunity of electric automated mobility services. *Rocky Mountain Institute and Mobility Transformation*.

Kaber, D. B., & Endsley, M. R. (2004). The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. *Theoretical Issues in Ergonomics Science*, *5*(2), 113-153. https://doi.org/10.1080/1463922021000054335

Keeney, T. (2017). Mobility-as-a-service: Why self-driving cars could change everything. *ARK Investment Management Research*.

Kolarova, V., Steck, F., & Bahamonde-Birke, F. J. (2019). Assessing the effect of autonomous driving on value of travel time savings: A comparison between current and future preferences. *Transportation Research Part A: Policy and Practice*, *129*, 155-169. https://doi.org/https://doi.org/10.1016/j.tra.2019.08.011

Leonard, J. J., Mindell, D. A., & Stayton, E. L. (2020). Autonomous vehicles, mobility, and employment policy: the roads ahead. *Massachusetts Inst. Technol., Cambridge, MA, Rep. RB02-2020*.

Li, Y., Tu, Y., Fan, Q., Dong, C., & Wang, W. (2018). Influence of cyber-attacks on longitudinal safety of connected and automated vehicles. *Accident Analysis & Prevention*, *121*, 148-156. https://doi.org/https://doi.org/10.1016/j.aap.2018.09.016

Litman, T. (2023). *Autonomous Vehicle Implementation Predictions: Implications for Transport Planning*. https://www.vtpi.org/avip.pdf

Liu, H., Shladover, S. E., Lu, X.-Y., & Kan, X. (2021). Freeway vehicle fuel efficiency improvement via cooperative adaptive cruise control. *Journal of Intelligent Transportation Systems*, *25*(6), 574-586. https://doi.org/10.1080/15472450.2020.1720673

Luetge, C. (2017). The German Ethics Code for Automated and Connected Driving. *Philosophy & Technology*, *30*(4), 547-558. https://doi.org/10.1007/s13347-017-0284-0

Manser, M. P., Noble, A. M., Machiani, S. G., Shortz, A., Klauer, S. G., Higgins, L., & Ahmadi, A. (2019). Driver Training Research and Guidelines for Automated Vehicle Technology [Tech Report]. https://doi.org/http://hdl.handle.net/10919/95178

Maurer, M. J. G., ; B Lenz ; H Winner. (2016). *Autonomous driving: technical, legal and social aspects*.

McDonald, A., Reyes, M., Roe, C., & McGehee, D. (2017). Driver understanding of ADAS and evolving consumer education. 25th International Technical Conference on the Enhanced Safety of Vehicles,

Merriman, S. E., Plant, K. L., Revell, K. M. A., & Stanton, N. A. (2021). Challenges for automated vehicle driver training: A thematic analysis from manual and automated driving. *Transportation research part F: traffic psychology and behaviour*, *76*, 238-268. https://doi.org/https://doi.org/10.1016/j.trf.2020.10.011

Michon, J. A. (1985). A Critical View of Driver Behavior Models: What Do We Know, What Should We Do? In L. Evans & R. C. Schwing (Eds.), *Human Behavior and Traffic Safety* (pp. 485-524). Springer US. https://doi.org/10.1007/978-1-4613-2173-6_19

Milakis, D., Kroesen, M., & van Wee, B. (2018). Implications of automated vehicles for accessibility and location choices: Evidence from an expert-based experiment. *Journal of Transport Geography*, *68*, 142-148. https://doi.org/https://doi.org/10.1016/j.jtrangeo.2018.03.010

Mitropoulos, A. M., T. (2022). *Conditionally automated driving: Mercedes-Benz announces sales launch of DRIVE PILOT* https://group-media.mercedes-

benz.com/marsMediaSite/en/instance/ko/Conditionally-automated-driving-Mercedes-Benz-announces-sales-launch-of-DRIVE-PILOT.xhtml?oid=53213668

Mynttinen, S., Koivukoski, M., Hakuli, K., & Keskinen, E. (2011). Finnish novice drivers' competences – Successful driving test candidates 2000–2009 evaluated by driving examiners. *Transportation research part F: traffic psychology and behaviour*, *14*(1), 66-75. https://doi.org/https://doi.org/10.1016/j.trf.2010.10.001

Nahmias-Biran, B.-h., Oke, J. B., Kumar, N., Lima Azevedo, C., & Ben-Akiva, M. (2021). Evaluating the impacts of shared automated mobility on-demand services: an activity-based accessibility approach. *Transportation*, *48*(4), 1613-1638. https://doi.org/10.1007/s11116-020-10106-y

NHTSA. (2022). *Levels of Automation*. National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.gov/files/2022-05/Level-of-Automation-052522-tag.pdf

Noble, A. M., Klauer, S. G., Doerzaph, Z. R., & Manser, M. P. (2019). Driver Training for Automated Vehicle Technology – Knowledge, Behaviors, and Perceived Familiarity. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *63*(1), 2110-2114. https://doi.org/10.1177/1071181319631249

Norton, P. (2021). *Autonorama: the illusory promise of high-tech driving*. Island Press.

Papa, E., & Ferreira, A. (2018). Sustainable accessibility and the implementation of automated vehicles: Identifying critical decisions. *Urban Science*, *2*(1), 5.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human factors*, *39*(2), 230-253.

Parkinson, S., Ward, P., Wilson, K., & Miller, J. (2017). Cyber Threats Facing Autonomous and Connected Vehicles: Future Challenges. *IEEE Transactions on Intelligent Transportation Systems*, *18*(11), 2898-2915. https://doi.org/10.1109/TITS.2017.2665968

Payre, W., Cestac, J., Dang, N.-T., Vienne, F., & Delhomme, P. (2017). Impact of training and in-vehicle task performance on manual control recovery in an automated car. *Transportation research part F: traffic psychology and behaviour*, *46*, 216-227. https://doi.org/https://doi.org/10.1016/j.trf.2017.02.001

Polders, E., Brijs, K., Brijs, T., Pavlou, D., Yannis, G., Winkelbauer, M., Salamon, B., Hausmann, M., Jost, G., & Calinescu, T. (2017). The implementation of Directive 2006/126/EC on driving licences-Final report. http://publications.europa.eu/resource/cellar/bbd8141d-e603-11e7-9749-01aa75ed71a1.0001.01/DOC_1

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, & Cybernetics*, *SMC-13*, 257-266. https://doi.org/10.1109/TSMC.1983.6313160

Roemer, E. (2021). *Van rijles naar rijonderwijs. Advies verbetering autorijscholenbranche [From driving lessons to driving education. Advice for improving the driving School industry]*. https://open.overheid.nl/repository/ronl-a3bb9c8e-b5ef-4987-add9-f54abe329fe9/1/pdf/bijlage-1-van-rijles-naar-rijonderwijs-advies-verbeteren-autorijscholenbranche.pdf

SAE. (2021). *SAE J3016 Levels of Driving Automation* https://www.sae.org/binaries/content/assets/cm/content/blog/sae-j3016-visual-chart_5.3.21.pdf

Sætren, G., Pedersen, P., Robertsen, R., Haukeberg, P., Skogstad, M., & Lindheim, C. (2018). Simulator training in driver education—potential gains and challenges. In (pp. 2045-2049). https://doi.org/10.1201/9781351174664-257

Schopfel, J. (2010). Towards a Prague definition of grey literature.

Shi, Y., He, Q., & Huang, Z. (2019). Capacity Analysis and Cooperative Lane Changing for Connected and Automated Vehicles: Entropy-Based Assessment Method. *Transportation Research Record*, *2673*(8), 485-498. https://doi.org/10.1177/0361198119843474

Souman, J., Adjenughwure, K., & Tejada, A. (2021). Quantification of Safe Driving. https://publications.tno.nl/publication/34639060/3JlniP/TNO-2021-R12632.pdf

Sparrow, R., & Howard, M. (2017). When human beings are like drunk robots: Driverless vehicles, ethics, and the future of transport. *Transportation Research Part C: Emerging Technologies*, *80*, 206-215. https://doi.org/https://doi.org/10.1016/j.trc.2017.04.014

Spulber, A. (2016). *Impact of Automated Vehicle Technologies on Driver Skills*. https://www.cargroup.org/wp-content/uploads/2017/02/IMPACT-OF-AUTOMATED-VEHICLE-TECHNOLOGIES-ON-DRIVER-SKILLS.pdf

Stanton, N., & Young, M. (2000). A proposed psychological model of driving automation. *Theoretical Issues in Ergonomics Science*, *1*. https://doi.org/10.1080/14639220052399131

Steen, A., Tsapi, A., Linde, M., Oskina, M., Hogema, J., & Tillema, F. (2020). *How to maximize the road safety benefits of ADAS*. https://www.anwb.nl/binaries/content/assets/anwb/pdf/auto/zelfrijdende-auto/fia-adas---study-finalreport_07102020-definitief-rapport.pdf

Strauch, B. (2018). Ironies of Automation: Still Unresolved After All These Years. *IEEE Transactions on Human-Machine Systems*, *48*(5), 419-433. https://doi.org/10.1109/THMS.2017.2732506

SWOV. (2021). *Young Drivers*. https://swov.nl/sites/default/files/bestanden/downloads/FS%20Young%20drivers_2.pdf

Tsapi, A. (2015). *Introducing Advanced Driver Assistance Systems (ADAS) into drivers' training and testing: The young learner drivers' perspective*.

Tsapi, A. V., J. (2020). *Kwaliteitsimpuls rijscholen: Onderzoek naar een rijscholenregister en kwaliteitscontrolesysteem [Driving school quality impulse: Research into a driving schools register and quality control system]*. https://zoek.officielebekendmakingen.nl/blg-946163.pdf

UN Regulation No. 157, (2022). https://unece.org/sites/default/files/2022-05/ECE-TRANS-WP.29-2022-59r1e.pdf

van den Beukel, A., van Driel, C., Boelhouwer, A., Veders, N., & Heffelaar, T. (2021). Assessment of Driving Proficiency When Drivers Utilize Assistance Systems—The Case of Adaptive Cruise Control. *Safety*, *7*, 33. https://doi.org/https://doi.org/10.3390/safety7020033

van den Beukel, A. P., van der Voort, M. C., & Eger, A. O. (2016). Supporting the changing driver's task: Exploration of interface designs for supervision and intervention in automated driving. *Transportation research part F: traffic psychology and behaviour*, *43*, 279-301. https://doi.org/https://doi.org/10.1016/j.trf.2016.09.009

van Driel, C., van den Beukel, A. P., Veders, N., & Huijboom, C. (2019). Driver training and testing in the era of automated driving: Status quo and future directions. 13th ITS European Congress 2019: Fulfilling ITS promises,

Vlakveld, W. (2019). Veiligheidseffecten van rijtaakondersteunende systemen. *Bijlage bij het convenant van de 'ADAS alliantie*.

Vlakveld, W. P., & Wesseling, S. (2018). *ADAS in het rijexamen; Vragenlijstonderzoek onder rijschoolhouders en rijexaminatoren naar moderne rijtaakondersteunende systemen in de rijopleiding en het rijexamen voor rijbewijs B*.

Watson-Brown, N., Mills, L., Senserrick, T., Freeman, J., Davey, J., & Scott-Parker, B. (2021). A complex system of learning to drive: The instructor's perspective. *Safety Science*, *136*, 105172. https://doi.org/https://doi.org/10.1016/j.ssci.2021.105172

Xu, G., Pei, H., Jiang, M., Chen, J., Wang, H., Zhang, H., & Liu, Y. (2023). High-Resolution mmWave SAR Imagery for Automotive Parking Assistance. *IEEE Journal on Miniaturization for Air and Space Systems*, *4*(1), 54-61. https://doi.org/10.1109/JMASS.2022.3226771

Yao, Z., Wang, Y., Liu, B., Zhao, B., & Jiang, Y. (2021). Fuel consumption and transportation emissions evaluation of mixed traffic flow with connected automated vehicles and human-driven vehicles on expressway. *Energy*, *230*, 120766. https://doi.org/https://doi.org/10.1016/j.energy.2021.120766

Ye, L., & Yamamoto, T. (2019). Evaluating the impact of connected and autonomous vehicles on traffic safety. *Physica A: Statistical Mechanics and its Applications*, *526*, 121009. https://doi.org/https://doi.org/10.1016/j.physa.2019.04.245

Yin, R. K. (2017). *Case study research and Applications Design and methods*. Sage Publications.

Young, M. S., & Stanton, N. A. (2007). What's skill got to do with it? Vehicle automation and driver mental workload. *Ergonomics*, *50*(8), 1324-1339. https://doi.org/10.1080/00140130701318855

Zahabi, M., Abdul Razak, A. M., Shortz, A. E., Mehta, R. K., & Manser, M. (2020). Evaluating advanced driver-assistance system trainings using driver performance, attention allocation, and neural efficiency measures. *Applied Ergonomics*, *84*, 103036. https://doi.org/https://doi.org/10.1016/j.apergo.2019.103036

Zhong, Z., Liu, S., Mathew, M., & Dubey, A. (2018). Camera Radar Fusion for Increased Reliability in ADAS Applications. *Electronic Imaging*, *2018*, 1-4. https://doi.org/10.2352/ISSN.2470-1173.2018.17.AVM-258

Ziebinski, A., Cupek, R., Grzechca, D., & Chruszczyk, L. (2017, November 01, 2017). Review of advanced driver assistance systems (ADAS). Computational Methods in Sciences and Engineering 2017 (ICCMSE-2017),

Appendix A– Interview Guide

The following questions on the mentioned topics are meant to encourage and guide the conversation.

1. Background
   Could you briefly describe your role and responsibilities at CBR? How long have you been in this role and did you work anywhere prior to this?

2. Examiner Understanding of ADAS
   In your opinion, do drivers clearly understand how these ADAS function? If not, where do you think their understanding is lacking?

3. Current evaluation procedures
   To your knowledge, how are the current driving tests addressing the use of ADAS? Is there any emphasis on these technologies, and if so, how?

4. Need for ADAS Evaluation
   Do you think there is a need to incorporate ADAS into the driving exam? Why or why not?

5. Incorporation Approach
   If ADAS were to be incorporated into the driving exam, in your opinion, which specific aspects would need to be evaluated?

6. Testing Challenges
   What challenges do you anticipate in evaluating a driver's knowledge and use of ADAS during a practical driving exam?

7. ADAS Matrix Feedback
   a. I've developed an ADAS evaluation matrix to assist examiners/students in the exam. According to you, what are its strengths, and which area(s) might need improvement?
   b. Questions about ADAS/Rows/Separation of LDW/LKA?
   c. Questions about Skills/Columns/Separation of behaviors?

8. Preparation for ADAS Evaluation
   In your opinion, what kind of preparation or training might be necessary for examiners like yourself to effectively evaluate ADAS use during exams?

9. Impact on Drivers
   How do you think incorporating ADAS into driving exams would impact drivers, particularly novice drivers?

10. Timeline
    Recently it came out that, ADAS is not in exam in 2024. If you were to incorporate ADAS into driving exams, what would be a realistic timeline to implement such a change?

Appendix B – Transcript of Interviews

Interview 1

Researcher: Arav Kharkwal
Date: 12/06/2023
Location: Microsoft Teams [Online]
Semi-structured Interview with Driving Examiner

The interview began with the researcher reminding the participant (driving examiner) of the consent form and seeking their agreement for an audio recording of the interview. The subsequent conversation is transcribed below:

Researcher: I will begin by giving you a short summary of myself and my research. My name is Arav. I'm a second year, master student at TU Delft studying civil engineering. My degree is in transport and planning. I was connected to Daniel, and the R&D department by Dr. Marjan Hagenzieker, my advisor at TU Delft. The topic of road safety was interesting to me, and when I got to know more about what CBR is doing, I was really interested in this opportunity to research how ADAS can be introduced in the driving exam. Now if you could please tell me a little bit about yourself, your role at CBR and how long you've been a part of the organization?

Examiner 1: I've been with CBR around 22 years now, I started in 2001 as an examiner. Well, there after that, I became a teacher for the RIS (Driving in Steps) Program. After that, I became a manager, an examiner manager with another division. I did that for about 9 year. After that I became the head of product management and was responsible for the content of the Dutch driving test. And in 2018, I transferred to become exam manager again. Um, and that's what I do now.

And I became a member of the expert advisory group of CA in 2017, and I will be until December 1st of this year. Then I will stop at that role, but I've been active there for a total of 10 years. The first four years in all kinds of projects, like the road user education project which was providing information for the 4th European driving license directive. And starting December 1st 2017, I became a member of the expert advisory Group. We organized workshops every year the last two or three before covid-19 were about ADAS. And we also do audits on driving tests in Europe and even outside of Europe. The last one we did was in Dubai, which was very nice and interesting.

Researcher: Well, thank you for that. All that is really nice to hear because I have been researching these terms and directives online. I'm looking forward to talking to you, someone who has worked behind the scenes on lot of the topics I cover in my research. Now I will now be sharing my screen to go over some things that will help give more context to the topics we will be discussing. Please let me know when you can see my screen.

Examiner 1: I can see your screen.

Researcher: This table by the SAE divided automation into 6 levels, from 0 to 5, with the degree to which automation takes over the driving task increasing at each level. Last year in June, the Mercedes-Benz driver pilot system was approved in Germany, making it the first Level 3 SAE system approved in the world. More recently, this has also been approved in a few states in the United States, namely California and Nevada. To summarize, only 2 Germany and USA currently have commercially available Level 3 systems for purchase. What makes this system Level 3 is that it's ability to continuously handle the driving task, while the driver can have their hands off the steering wheel, however, still be ready to take over the driving task when requested by the vehicle. Level 2 on the other hand, which is what Tesla's Autopilot is classified as, requires that the driver's hands be on the steering wheel when the system is active.

Researcher: I will now begin the interview by talking about ADAS specifically. My first question to you is "In your opinion, do drivers clearly understand how these ADAS function? If not, where do you think their understanding is lacking?"

Examiner 1: I think there's a big knowledge gap amongst the car drivers, and it goes for all ages. Elderly people, like me I might say, I had my driving test in 1982 and it was very basic. But it was a permit for life, as long as the fitness to drive is not a problem. You can drive with it till the age of 75. But you never get additional training on developing rules but also on developing technology. What I think is happening is that people are educating themselves. It is the only way that works as you would expect a responsibility from car sellers and car manufacturers.

But the last car that I obtained was a Lync&Co, and I ordered it over the interview via a lease plan that CBR use, and I picked up the car and they asked if I had any question. I said no fine and they said thank you, have a nice day. And due to my background and my work I know a lot about these cars and the systems in it and the limits of it, but I think there is quite a way to go and people have a very basic driving license and they can drive everything. All systems allowed by the government can be in the car and be used by the drivers.

So, I think it's quite a risk, because you just don't know what the car does, what it will do and what your role is because the roles of the driver will be more complex. Um, During the process of climbing in levels of automation. Because a lot of people think in a few years I will have a self-driving car. I will get in and type in my destination and start reading the newspaper. Which is very old-fashioned, of course. I mean, of course any reader. But I think it will take years before that is the case because the cars will be more complicated and it will ask more from the abilities of the driver, their knowledge, their ability, their skills. And they are not trained for it currently and I think there is quite a gap.

Researcher: You spoke about something really interesting here, which is the car buying experience. And since you have the idea of the other side, in the Netherlands, in your opinion, do they plan to introduce the dealership aspect of it like because the deal dealership is an important point of knowledge since you know we don't have the driving test again and things like that. That's like you said that's one of the ways people first learn about ADAS. So, in the

Netherlands, you think dealerships could do more and do you have any insight on whether there are plans for the same in the future?

Examiner 1: I guess it varies from one manufacturer to another, because the only appeal is their sense of responsibility. And I think in daily life the practice will be that they ask the new customer, are you familiar with the new car, do you have any questions, would you like me to tell you more about it? And the customer, especially men, they all think they know enough so I think the standard answer will be, “no I’m fine I’ll read a book”. I think there’s a comparison with the new cupboard from IKEA. It has a very thick manual and nobody reads it and starts to work on it. And when they don’t succeed, they get the manual and then figure out what’s wrong. I think for cars it’s the same. So maybe it would have to be an obligation for people selling cars to inform anew drivers about the abilities of the car. So, I think an obligation would be more effective than the current system.

Researcher: Okay, yeah, thank you. Very interesting you say that because during my review of literature I found that drivers learn about systems mostly through trial and error and only when they encounter a problem do they open the manual or go on the internet.

Now I’d like to discuss driver testing procedures. My question is “To what extent is ADAS and other technologies covered in the driving exam?

Examiner 1: I don't think I quite understand the question, can you repeat it please?

Researcher: Yes, sorry. My question is “Does the current way in which examiners evaluate students, covered ADAS or any other technologies?” I’m trying to analyze whether new evaluation procedures for examiners may be required or might current evaluation methods already cover ADAS and new technologies?

Examiner 1: Until December 1st 2016 we did not allow ADAS in cars during the driving test. They had to be switched off. But over time that was not acceptable anymore. In fact, it was even quite immoral because there are systems that prevent collisions and are there to help prevent people getting hurt. And for that reason alone, you cannot switch them off. Second reason is that there are systems that can be switched off and systems that can’t be switched off.

On 1st January 2016 we started allowing all of the systems except the fully automatic parking because that is just pushing a button and doing nothing, not true really, but that was a risk at the time. But apart from that we allowed everything. And we educated the examiners in handling this and judging on what they see, but the driver is always personally responsible for the behavior of the car. So, if the system does something, to the way the car is driving, the driver is still responsible. We use one example to explain it to the examiners. We use more but I’ll explain one that was very effective. When you have ACC that is 100 km/hr., you’re following the truck and then it is 80 km/hr. When you go on the right to leave the highway, the car speeds up again because there is no obstacle anymore. And that’s where we expect the driver to reduce the speed, by switching off the system or using the brake or whatever. That was an

example to explain that the driver is always responsible. Even when there is no system, or several systems, the driver is the one responsible. That's how we explained it at the time and in fact still do.

Researcher: This topic is an important part of my research in terms of explaining things to the examiners. Could you please tell me more about how this training was conducted and what was taught?

Examiner 1: We have a yearly education program which is part of the third European driver's license directive, Annex 4 more specifically. The directive is such that you have to train examiners every year in subjects the are related to the driving test. We used the training in 2015 or 2016 I guess, to let them experience driving a car with all these systems in it. We bought several cars that we have in Leusden in the training center. Every examiner was driving with a teacher. So, two examiners and a driving teacher were driving all day to experience what it does to a car and to the way it drivers so they were made familiar with it so to say.

Researcher: Has something like that been continued every year? I guess my question is "Is it a yearly thing that examiners get to experience the new technology on the market?"

Examiner 1: It should be yeah.

Researcher: Alright. So, to be clear, it is not a part of the official introduction? I was in the Leusden training center and as a part of my pilot experience which was with two examiners in training and one experienced examiner guiding/assessing them. Is it part of the driving examiner introduction training program yet?

Examiner 1: I assume it is. I'm not sure about the exact material as I don't go to Leusden that often anymore. At CCV, we have our own trainers, we call them practical driving instructors. And I am their manager so I am responsible for their training program and the education of our examiners.

Whenever we train someone to become an examiner at CCV, there's comprehensive practical training since not everybody has their personal truck, different from how it is for cars. So we hire trucks and we train them in driving themselves in duos. There's one behind the wheel and one on the right training to be an examiner and judging the system and how it works. So yes, it is part of our basic training.

Researcher: Thank you so much. Just stemming of my last question, do you believe there is a need for driver use of ADAS to be evaluated during the practical driving exam?

Examiner 1: What we still do is evaluate the role of the driver or novice driver. And it's always influenced by development of rules, technology, environment, and as it's getting busier on the street. What has not changed is that we still have an opinion on the driver next to us and we're looking at what he or she is doing. And whether it's okay or not okay, resulting in fail or pass. But the task of the driver is developing under the influence of developing technology. So, it

automatically becomes a part of our work. But we focus on the role of the driver, and their responsibility towards the safe operation of the car.

Researcher: Thank you. You said that you gave driving examiners instructions on how to evaluate the use of ADAS in the driving exam by emphasizing that they're still evaluating the operation of the driver and not the car. Since this is important for my research, could you please tell me about other ways that were discussed or used then?

Examiner 1: Well, what we gave instruction for the most important part. We have, of course, our coaches in Leusden who accompany examiners during their work. We encourage examiners to ask for support whenever they have doubts or questions. So, we also encourage them to develop themselves in this subject. When necessary, the yearly training program has time allotted to inform them about any new development.

Researcher: Yes totally. I conducted my pilot experiment in Leusden with the examiners in training and their coach. It was really insightful to hear the conversation between the examiners and coaches during and after the ride. The details and specificity of that was very interesting, without their being any discussion of technology, and the main focus on safe operation of a vehicle and how they interpret the assessment matrix. So based off this, my next question to you is "What challenges do you expect in the future for incorporating this into the driving exam?"

Examiner 1: I think the biggest challenge is to keep up with development with respect to the driver. For instance, I was in Paris a few years ago going around the perimeter of Paris. I was with the EAG, the group I am a member of. And there were two cars, a Peugeot and Renault. One of them was called an SAE 3 level car with systems that could take over during traffic automatically. I would say it was a bit simple and amateurish. You compare it with a way you normally observe a overtake action by a human. The car in this case was reducing speed and speeding up during this. It was waiting for a certain space on the lane next to it and it waited for a long time and the speed was not okay. But eventually it succeeded in overtaking the car in front of it. But of course, that was years ago and the systems keep getting better and better. So, at some point, like the Mercedes we spoke about in Germany you come to judge the driving skills of the car and not the human in it. And I think that's quite a challenge because it is not only the role of the driver changing but I also think there's a change coming to the authorities that are responsible for the cars. Originally it was RDW responsible for checking screws in cars and what not and we were responsible for the person driving it. I think that's quite the challenge to combine the knowledge of RDW and CBR to have quite a good opinion on the driving skills of a car. And the responsibilities of the driving sitting in that specific car. That's quite a challenge.

Researcher: I know that Daniel and others in R&D are working on stuff along the same lines. This is also something I had in mind during my research as I want to create something that is not

obsolete when newer and better technologies enter the market. I will now share my screen with you to show you what I have developed to help examiners evaluate candidates.

----------Part 2: ADAS Matrix----------

The process was as such: I compiled the ADAS in the market currently and divided them into whether they take-over the driving task at any time or help the driver in making decisions that could help avoid hazard. So, like you mentioned automatic parallel parking earlier, it was not selected by me as well as it does not exhibit operational knowledge of parking a car. Although the driver still has to monitor this maneuver that is undertaken by the systems in the car. After selecting the ADAS, I started to shortlist behaviors that drivers need to demonstrate to prove to the examiners their proficiency or lack of it with the ADAS available in the car. I will give you a few minutes to go over this and then we could discuss more.

After 2 minutes

Researcher: At a first glance, what do you think are the strengths and weaknesses of this developed matrix?

Examiner 1: I think something we should think about is the way we test it. There is driver responsibility in relation to the ADAS systems. If we take the first one say for instance Parking Assist, “Understand when to activate/deactivate” is something that maybe the theory exam covers better than the practical exam. This is because we have a test of 35 minutes, until now anyway. So, I think it’s almost impossible to test all the systems available. The differences in naming of these systems between manufacturers, along with technical differences like cut-off points and color of the lights also complicates this further. But I think you already have certain levels, like behavior which is a theory thing and operational control is how you use it. Yeah so, I think the biggest challenge is to find a way to incorporate this into the current testing procedures, both theory and practical.

Researcher: Um, thank you. Yeah. So, I guess that would be the overall thing of it. Now we what we'll do is we'll just go through this specific ADAS. And just to give you a background like so these parking assists LDW, all these things, like I have included this over here. But the examiner is not evaluating the system. So, it really doesn't matter in this matrix. My next question for you is “Take for example Lane Departure Warning and Lane Keeping Assist, with their main function being to help keep the car in the lane. Should there be a difference in how these two systems with the same function are evaluated?

Examiner 1: So, Lane Departure Warning gives you an alert while Lane Keeping Assist not really taking over but assist by maybe putting pressure on the steering wheel?

Researcher: Yes, which also makes it harder for an examiner to observe.

Examiner 1: Yes, that is also quite challenging because as long as the car is not fully automatic, it is up to the driver. As examiners, we want to know whether a driver is able to drive in a straight

line. It's one of the basic driving skills we judge. And when you use the Lane Keeping Assist it is not obvious for the examiner as they might not be able to see, hear, or feel it. Thus, it becomes difficult for the examiner to know whether the car is driving correctly, the driver, or a combination of both.

I do not really have a solution for this issue. I think the only way to do the job is to develop it further and further to a situation where we still do what we are doing now, which is observing the candidate's operational tasks with or without these systems. A lot of my colleagues think that is not okay since the car is taking over the part of the driving task of the driver but I still think that you can still judge his driving skills, and it will not become easier. On the contrary, it will become more complex. What we still see in driving lesson situations today is that the driving instructor buys a car and switches everything off as it too complicated. There will be a moment where you can't switch it off, like lane keeping assist and then we'll have to deal with it anyway. And that goes for both the driver and the examiner.

----------Part 3----------

Researcher: With it being complicated to observe certain operational tasks during the practical exam, what role do you believe the theory exam to play in this?

Examiner 1: Yeah, I think both. Like the hazard perception test. We're talking about how we test it and how we use the pictures which don't test anything really. I was in Vienna two week ago. There was this manufacturer called Jellylune from the UK that demonstrated this technology. And the big advantage of it is that you can make situations on the screens that you can not make in traffic. Rain, icy roads, snow, driving in the middle of the night etc. Which is not possible in the driving test, where you have to use what you need during the 35 minutes. I think this goes also goes for ADAS, not the hazard perception. You will have to look for a good combination of the theory test and the practical test. What can you do in theory and what do you have to do in the practical test.

Researcher: So, I understand that to mean that you can't just cover ADAS on one of the other. A holistic approach that covers all the required knowledge. So, thank you for that. This also bring my to my next topic which is the driver behaviors. When I was compiling, sorting, and listing then, there were a few discrepancies I noticed in literature in regard to what should be evaluated and what should not be. For example, ACC, some people think of it as a convenience feature to be used when fatigued or when the driver wants to reduce their workload in relation to the driving task and thus it should not be tested as it doesn't demonstrate operational control of a vehicle when engaged. But it is still a safety feature. However, literature also suggests that the takeover scenario when the driver takes over the driving task is safety critical. Thus, other argue that ACC use should be evaluated during a driving exam.

Coming to the CBR guidelines for ADAS, I noticed that they did not explicitly mention this. One of the reasons could be that the candidate does not face such a situation during the driving exam where a takeover needs to be performed. Stemming from this variability in test conditions

due to which certain ADAS may not be used during the driving exam, my question to you is “Do you believe that certain situations such as a take-over scenario may be better evaluated using moving images?

Examiner 1: Yes, I guess so. Yes. Because there you can create a situation where you can test the role of the driver. But the lack of reality is that you’re looking at a screen and click a button or tell somebody what you see. It’s not really driving and acting. A second possibility is that – I was in Norway several times for my job and what I liked very much is they divide the driving task on the basis of the GDE Matrix. You’re familiar with it, I guess?

Researcher: Yes.

Examiner 1: And they say well “Level 1 and 2 is that is evaluate in the driving test, and Levels 3 and 4 is more for the driving schools.” I guess with the increasing complexity of the driving task we should follow the same path in the Netherlands. But it would mean that we have to do a lot in the driving school world. They will have to be more professional than they are currently. This is not true for everyone, just a part of the driving schools. It’s not yet the situation where we leave things to driving schools, but yes, I think we should develop in that direction so that you can have a combination of a qualified training system and a driving test that follows the education so to say.

Researcher: So, based on the same topic, there have been papers by Vlakveld and more recently the Roemer report. The Roemer report mentions the role of driving schools and the disconnect between them. Do you have any updates on your side as to consequences of this report? Because what I know, and correct me if I am wrong, is that driving schools dictate their own program based on the way CBR conducts the driving test. And except for a few program like RIS, there is not concrete program that teaches drivers all the requirements listed by CBR.

Examiner 1: No not yet. I mean Um, And, If I say not yet, I'm Implicated it will be there in time, but I’m not so sure about that because it is also a very political issue. The current Dutch government doesn’t want to be the government that makes getting a driver’s license more and more expensive as candidates are also voters. But I hope that the Roemer report is the beginning of developing a system that standardizes driver’s education. Because what you see now is not based on standards. When I was a driving instructor, while I was still working as a policeman, you were teaching the things you meet in traffic or something along those lines. And that’s no longer the best way. I guess you have to have a curriculum in which you guarantee that everything you need to know is met during the education. Therefore, you need a curriculum and a certain grip on the driving schools. And this is not the current situation. So, I guess when you try to replicate the situation in Norway where we test the level 1 and 2 and leave levels 3 and 4 to the driving school. For this to happen we will have to re-arrange the whole system in the Netherlands to make sure that everything is being taught in the right way during the education process, and that is not the system yet.

Researcher: And I believe, correct me if I'm wrong, that Norway or also is exploring using simulators as a part of the driver licensing process? I read a few reports about that but wasn't sure.

Examiner 1: Last time I was there several years ago, there was no simulator, I didn't see it anyway. We are now within CCV, we are looking at simulators for the professional training of truck drivers and looking at possibilities. But I have been driving a truck simulator and was not impressed by the quality of it. I guess in time they will develop and become cheaper and there may be some kind of turning point. After this point it will be possible to let the simulator take over part of the education. And in time, even a part of the driving test.

Researcher: All that is very interesting to hear. One of the things I learnt during my research was the many stakeholders involved in not only the Rijprocedure B, but also in the decision to modify a part of the driving test. My next question for you is "what kind of education/training will be necessary to make sure examiners are well equipped to evaluate candidates on their use of ADAS during the driving exam?"

Examiner 1: Well, automatically, when you develop a system using both the theory and practical test, you have to train the people who take the test as well, on the same topics. Because the more you put into a driving test, the more you will have to train the driving examiner because otherwise he will ne be aware of the things they are testing. It would mean spending more time and money to educate our examiners on these developments.

Researcher: Okay yeah, thank you for that. And just the last question to conclude "Do you have a timeline in mind as to when ADAS might be more integrated into the driving exam, something as a next step to the current ADAS guidelines in the Rijprocedure.

Examiner 1: Well, I heard something about a position paper from CBR which states that it will not be possible to test ADAS within the next years. And I was a bit disappointed to read that as I do not agree. I think we should be the leading organization in this and take initiative. There's two paths. The path of reality and that of ambition. So, I'm not quite sure on a timeline, but we have to speed up to keep up with the developments. There are lot of organizations in the Netherlands, and outside of the Netherlands which are going faster than CBR. So, if we don't develop fast enough, we will not be relevant in time as other organizations will take over our responsibilities. We have the knowledge, so we need to be a part of it to ensure that the procedures are up to speed. We realize that the image of everyone sitting in the car and not doing anything is not correct and it will take years and years if we even reach that situations. There are several factors such as the will of the people. My wife has a convertible Audi with a manual gearbox and I love driving it, even though an automatic gearbox is better. The second part is the traffic, as it is far too complex for cars to be totally independent to drive. When you compare it to flying an airplane, the airplane is in a corridor where nothing is happening and it's flying in a straight line most of the time. Thus, the pilot has time to take over from the autopilot.

This is not true with road traffic as it includes children, birds, dogs, any a lot of things happening. It's far too complicated to be fully automatic.

Researcher: Yeah, totally. You spoke about visiting some countries as a part of your jobs and that other organization are making advancements. But during my research, I only found licensing organization in Netherlands, Norway, and Germany with specific provisions for ADAS. Could you please tell me more about the progress you saw in other countries?

Examiner 1: Well, in all the countries that I visited, everybody is trying to deal with the challenge. But I also see that the level they have reached is not very high yet. So, I agree with you about Norway, Netherlands, and Germany. But they're also not developed systems we could use. They're all on the same level.

Researcher: Thank you for that. Which is why I feel like it's a great opportunity for me to be able to do this with CBR and for the future as well. With that, I conclude this interview. Thank you so much for your time today. Is there anything else you would like to discuss today? Any questions or comments you may have on my research?

Examiner 1: No, not at the moment.

Researcher: Thank you so much for your time again. I really enjoy this conversation with you and I got a lot of a lot of insight. I hope you have a good rest of your week.

Examiner 1: Thank you, you as well.

Interview 2

Researcher: Arav Kharkwal
Date: 20/06/2023
Location: Microsoft Teams [Online]
Semi-structured Interview with Driving Examiner

The interview began with the researcher reminding the participant (driving examiner) of the consent form and seeking their agreement for an audio recording of the interview. The subsequent conversation is transcribed below:

Researcher: I will begin by giving you a short summary of myself and my research. My name is Arav. I'm a second year, master student at TU Delft studying civil engineering. My degree is in transport and planning. I was connected to Daniel, and the R&D department by Dr. Marjan Hagenzieker, my advisor at TU Delft. The topic of road safety was interesting to me, and when I got to know more about what CBR is doing, I was really interested in this opportunity to research how ADAS can be introduced in the driving exam. Now if you could please tell me a little bit about yourself, your role at CBR and how long you've been a part of the organization?

Examiner 2: I have been working at CBR since 2008. I am not so good at counting but for a long time (15 years). I started as an examiner with CBR and due to having a neck injury I started doing alternate work which brought me to my current position which is Coordinator of

aggression and violence. In English it sound even worse than it does in Dutch. I am responsible for the employees that encounter violence and aggression with our candidates. The employees can make a normal notification of that in my direction and I will respond to the candidate that did not behave well. I have been doing this for a few years now, and I am in the office in the R&D and that is how we connected. I heard you were looking for an examiner so I am happy to oblige.

Researcher: Well, thank you for the introduction and your time. Now I will now be sharing my screen to go over some things that will help give more context to the topics we will be discussing.

Researcher: This table by the SAE divided automation into six levels, from 0 to 5, with the degree to which automation takes over the driving task increasing at each level. Last year in June, the Mercedes-Benz driver pilot system was approved in Germany, making it the first Level 3 SAE system approved in the world. More recently, this has also been approved in a few states in the United States, namely California and Nevada. To summarize, only 2 Germany and USA currently have commercially available Level 3 systems for purchase. What makes this system Level 3 is that it has ability to continuously handle the driving task, while the driver can have their hands off the steering wheel, however, still be ready to take over the driving task when requested by the vehicle. Level 2 on the other hand, which is what Tesla's Autopilot is classified as, requires that the driver's hands be on the steering wheel when the system is active.

Researcher: I will now begin the interview by talking about ADAS specifically. My first question to you is "In your opinion, do drivers clearly understand how these ADAS function? If not, where do you think their understanding is lacking?"

Examiner 2: Well, that is a good question. I think many people understand the simpler ADAS tools like cruise control. But how to really use it in a smart way? That is where the intention of ADAS is to make traffic safer and be able to respond earlier and in a safer manner than without ADAS. And what I see now is that people use them to make it more comfortable at some points but they do not understand the consequences. For example, using the automatic cruise control which keep your distance. I think a lot of people use it and then change lanes, without realizing it is still active. However, if there is not a car in front of them anymore, the system will start to accelerate. And to recognize that in other people, that maybe they're going too fast because they're using it in the wrong way. That is where we are still lacking understanding of the tools available.

Researcher: Thank you. That bring up an interesting point in that it's the interaction of human and automation. And while people know the basics of these systems, they should be more aware of the limitations. My next question to you will be about the examiner side of things. My question is "How are the current driving tests addressing the use of ADAS? And is there an emphasis of these technologies?"

Examiner 2: Well, I have not been examining for a few years, but I do not think there's a big difference in how I used to do the examination and how they're doing right now. And I do not think it plays a big role in how we judge the performance of the candidates. So, if they use it in a correct manner, and if them using it leads to a dangerous situation then it is not okay. But that is where it stops. We do not take in our judgement that they are using it. So, it is not an extra scale or an extra way to assessing the performance that directs them to use it for a certain period of time or in certain situations. Currently it is not that big of a role and it is up to the candidates. Some of them practice it with their instructor, and some of them even practiced the part we were talking about, in terms of the extra information that one needs to process. But that does not happen a lot. Most instructors just teach the candidates the basics to be able to pass the exam. It is not something we take into our judgment, so if they are not practicing it in their lessons, and do not use it during the driving test, we examiners will not evaluate them on it.

Researcher: This bring me to my next question "Do you think there is a need to incorporate ADAS into the driving exam in some way?"

Examiner 2: I am thinking of navigation, is that considered an ADAS?

Researcher: Technically it is, at Level 0. But the focus of my research is more on ADAS that interferes with the driving task directly or indirectly. Som because of that, I do not focus on it in my research.

Examiner 2: At some point they started testing the independence of the candidate by giving a certain goal to start driving to. In the beginning there were three options, we told them to go to the sporting facilities. And they will be able to know it because they practiced it. Or we would give a cluster assignment where we tell them to turn right at the first junction and go left on the second. The third option was the navigation system, and we could choose which one we wanted to use at that time. Over the years this resulted in just using the navigation system as a way to test independent driving. And now it is an obligation to use the navigation for 10-15 minutes. We ask them to put in the address but also be able to concentrate on the route and on the traffic. Even there, we judge on safety, but they are obligated to use the navigation system. I think it would be my preference to do something like that with ADAS. Where the most important ones, the ones that people use the most and have the most impact on safety ; well, if you have that clear then you could say they are obligated to use the at least this, this, and this ADAS system for 10-15 minutes of the exam. And you could possibly divide it into where they use navigation, and where they use ADAS. I think it will help traffic safety in the long term if people start learning to driving in this phase. This will allow them to get used to part of the new technologies that continue to become available to more people.

Researcher: Thank you for that. I was aware as to why the navigation system is used, to address the high levels of the GDE matrix, but I was not aware of how it came into being in the current driving test. So, thank you for your insight. You already answered some parts of my question in regard to the criteria for which ADAS should be tested by saying those that are safety critical. Is

there anything else that you think will help categories which ADAS system or function should be evaluated?

Examiner 2: No, safety is the most important part and, in my head, I am no questioning which ones impact safety. I think all of them impact safety and there are levels. That is up to you and you are doing the research and I am not going to interfere with that.

Researcher: Yes, I have thought about it and it is an interesting point because safety is the main goal of all these systems. Through the course of my research, I have found that these systems not only differ in safety based on the levels, but also by manufacturer and model. One manufacturer might have a safer system them another, while the objective of both is safety. So, depending on the testing car, it may even be a little unfair to test. And I know ultimately, I know that the examiner judges the safe operation of a vehicle by a candidate.

Researcher: Now focusing more on evaluation. My next question to you is “What challenges do you anticipate in evaluating a driver if ADAS was to be made mandatory in the driving test?”

Examiner 2: I think introducing it in the driving exam could be challenging because it is also about interpretation. We see the same thing with the navigation aid. We expect them to put in the address themselves. But the examiners also includes old people and one may say “use that button or that one”. While another examiners, if a candidate is not able to input an address, just puts the address for them as they want to see the candidate use it. So, to get that in a uniform way to get the colleagues understand what they are judging and what the important things are in the judgement, and the link to safety is always important. There are things in the exam that a candidate should know, but if they do not use it or do not know about it, but it does not impact the safety at that moment, even if you know that it could affect safety in later moment, then still we will not be able to judge.

Windshield wipers for instance. Everybody should be able to use them correctly. But if a candidate does not start to use them and it does not rain, we are not able to evaluate them on their use of it. I think the same complication will occur with ADAS. If they engage one of the systems and start using it, albeit incorrectly with no consequences for safety, it is very hard to make that method so heavy that it could impact the outcome of the exam. That is frustrating for examiner because they find it important. So, I feel the mindset to get people to use it and to evaluate it based on that could be a challenge.

Researcher: Your first point was about interpretation by examiners. So ultimately ADAS evaluation has to be something that is unform in terms of guidelines but also in terms of what examiners interpret it to be. Your second point was that situations where ADAS has to be used may not occur, which I think is an important point. All of these systems still have their limitations and weather is one that is a limitation for all due to the increased use of sensors and cameras in modern cars. Thus, if a limitation is not experienced during the exam, examiner cannot evaluate it. It kind of becomes an unfair verdict as examiners do not know whether the driver knows the important operational limitations of the systems available to them.

Examiner 2: Actually, that is already the case. I once had a candidate that could explain to me how windshield wipers work, but at some point, when we were entering the highway and it started to rain all of a sudden, the candidate was not able to switch the wipers on before entering the highway. If that had not happened, the driver would have probably passed the exam. So, there is also unfairness in the rain that does happen because the candidate was able to demonstrate the theory perfectly. So, what you ask is already the case, but I think this will add up to the gray area.

Researcher: So, one way maybe around that is a more comprehensive approach. With the driving exam being only a part of the process to get a license and the restricted time during it, the theory exam could also play a part in evaluating at least some aspects that cannot be covered in the practical exam. My next question to you is “What are your thoughts about material in theory exam that can cover some of the things a practical exam cannot?”

Examiner 2: think it will help to get people to at least get into the material will be helpful. Awareness will be bigger with that part included in the theoretical exam. If you ask me about the ideal situation to make sure that the candidate knows the theory as well as how to act in traffic. While the part about using the car could be an extra exam or an extra test where you go to an area where situations can be created for the candidates. So, you can make sure they test at least five out of ten important things. We do a similar thing with motor exams now, by doing special maneuvers in a special area. I think that, and it is a big change so I understand it will not be easy. But I think to cover parts of this, I think there should be conditions situations where you can make sure. That could be a physical area or a simulator.

Researcher: That is really interesting. Because the more I research the more I am convinced that this gap keeps becoming larger. Thus, the more we lag behind, the more we will need to catch up. Because eventually we may need a simulator as that’s where things seem to be heading.

----------Part 2: ADAS Matrix----------

I will now share my screen with you to show you what I have developed to help examiners evaluate candidates. The process was as such: I compiled the ADAS in the market currently and divided them into whether they take-over the driving task at any time or help the driver in making decisions that could help avoid hazard. So, as you mentioned automatic parallel parking earlier, it was not selected by me as well as it does not exhibit operational knowledge of parking a car. Although the driver still has to monitor this maneuver that is undertaken by the systems in the car. After selecting the ADAS, I started to shortlist behaviors that drivers need to demonstrate to prove to the examiners their proficiency or lack of it with the ADAS available in the car. I will give you a few minutes to go over this and then we could discuss it more.

After 2 minutes

Examiner 2: And I think the knowledge of ADAS is what you want to put in the theory exam? Or do you want to put something like that in the practical exam?

Researcher: That is still evolving. But in this case what I mean by knowledge of ADAS – knowing when to turn it on or off. Say like rain, the candidate should demonstrate adapting the car to the weather conditions.

Examiner 2: Yes so, it is like some questions we do before the exam, the check before, yes, I understand it. So, do you just integrate these questions in that part of the exam?

Researcher: Yes, as the limitations mostly come as a result of conditions the sensors and cameras are exposed to. Do you see any weaknesses in this matrix?

Examiner 2: I think with "#2", you mean that if they are using the ADAS like self-steering, keeping their lane. You could check your phone because the car keeps it at a distance. Is that what you mean by that, that the car is doing things by itself and they keep their concentration?

Researcher: Yes, essentially. They keep their concentration and do not do anything that could distract them from the driving task.

Examiner 2: it is good to pay attention to that but I don't think we drive long enough during the exam to be able to test something like that. Maybe outside of the Randstad they are on the highway a little bit long and in a constant speed and lane. But I do not think it is long enough to be distracted or seduced into doing other things as it is 2-5 minutes but not 10 minutes of driving just under ACC. But it is very important.

My husband drives a Tesla and if I am in the Tesla and I am going to Arnhem, I get seduced into checking my phone. I then have to remind myself that it is not okay since I am still in traffic. But that realization happened after a certain time. It doesn't happen when you just get on the highway or thinking about leaving the highway. When I think about the exam, especially in regard to certain locations such as Rotterdam, there are no situations where you are using these systems long enough for distraction to be a factor.

Researcher: Thank you. Are there any other comments or questions you have on the ADAS matrix?

Examiner 2: I imagine you have already tried to take things out and merge them into categories. But it is a bit much if you add this to the normal. It needs to be more compact but I understand what you have in there and how you want to use it. And this format already connects to the way us examiners work so it will be an easy transition for my colleagues.

Researcher: It did not connect this well until a few weeks ago. During this I read the Rijprocedure again and think it is a great document because it covers so many things especially the situations encountered on the road.

Examiner 2: there is a lot already in the Rijprocedure, and you just need to translate it into the new situations, by maybe adding a few words. But the philosophy behind the driving procedure is very sturdy. It is clear with what it requires and it lists all the things. It is a small book, but every time you read it you spot something new.

Researcher: Yes totally. I had not read it in a couple of months so reading it again was beneficial to my research.

Examiner 2: Can you read it in Dutch or do you translate it into English?

Researcher: I translate it into English.

Examiner 2: you did a good job.

----------Part 3----------

Researcher: Thank you. I will stop sharing my screen now. My next question for you is “How do we prepare examiners to this new role of technology in cars?”

Examiner 2: Well, I know that they have been training on ADAS for a little bit and the last time they had the cars available to them, they had a lot of options to experiment with. But I think you need to pay attention to the level that examiners have such that it’s at a high level for the whole group. Some will be better, some will be worse, but at least there needs to be a certain level in understanding and how to use it themselves. And there are colleagues that will be quick to understand and they are already using it, along with them being really interested in the topic. But at the same time there are colleagues that will have a hard time keeping up with the new technologies and consequently judging the candidate’s use of the same. You need to have the skill yourself to judge if another person has the skill. So, I think that can be a challenge and it is going to take time to get all the examiners through this kind of filter to see if the level is good enough. They all have to go to Leusden, all have to practice, and then have to be tested to see whether their level is good enough and be tested on that and then determine if they need extra practice. I think there will be examiners that will need extra attention to be able to evaluate ADAS use during the exam.

Researcher: Thank you for that. My next question is from the point of a novice driver. “How would novice drivers feel about using ADAS in the exam, say if 10 minutes of the exam are dedicated to exhibiting skills with ADAS.”

Examiner 2: I think that it will be much easier for them because they understand it much better if I were to look at my sons. They understand the technology and benefits much better. I have been raised without everything so I am still having to get used to it. My brain has to get a new mindset about certain situations, what you do yourself, what you have let go. And I think if you train new drivers from the beginning with this technology and you integrate it into their schooling and I think they will be why is this so important why is it so important, we will just do it for a little bit.

I think this will be easier for them than the navigation because that has more to do with the different set of skills. With navigation they have to pay attention to the route, and it is really good for the traffic and you have to translate the route. And ADAS is less complicated. There are

things you need to be aware of, but if you are trained from the beginning on those thing it will become much easier.

Researcher: My next question is “What role do you anticipate driving schools to play in order for ADAS to be implemented successfully into the driving exam?”

Examiner 2: They have a big role and a big resistance because as you said in the beginning, there is a big difference between the brands and to what extent it impacts safety. Some will already have their cars now, but some of them might have to make additional investments in the form of a car and learning it themselves and thus investing in education as well. So, it is not an easy group. There do exist very professional driving schools, but there will also be some of them that are resistant to change. They do not like investing and want to keep things as they are. Young people are already happy when they get into a modern car with a lot of gadgets and that is how they are viewed, as gadgets. And it is our job to explain that they are there for safety and need to be used in a certain way. They get excited about the “no hands” aspect of driving. Okay you do not have to work that hard but still keep your hands on the steering wheel. I think they will have fun but there is going to be a group of instructors that will be hard to convince for the change.

Researcher: Based on this, I would like to tell you about an anecdote from my field experiment yesterday. The examiner told the driver that it is also important to know when not to use a certain ADAS, as opposed to using it all the time just because it is there.

Examiner 2: And you have to get to know the system. The Tesla has some flaws in the system and that can really frighten you if you get alarms when there is nothing going on. It sometimes think you are not in the highway and sideway and think you are only allowed to go 30 km/hr. There are roads where I know it is going to interfere with other roads, and I know not to engage the self-driving distance and cruise control thing. And that is interesting too. And I am thinking about when not to use it. In busy traffic for instance, using cruise control where I can see several cars ahead, I can adjust my speed much better in that situation as compared to adaptive cruise control.

Researcher: This bring me to my final question. With there being so many stakeholders in this process and the recent news that came out that ADAS is not going to be in the driving test next year, do you anticipate a rough timeline by when ADAS might be implemented into the exam?

Examiner 2: ASAP. We are already, well, you said it before, that the gap between the old way and the new way is getting bigger and bigger and what we’re going to ask the industry to do now is a bigger step than it would have been before if they have been told to integrate in their education system with respect to buying certain cars and educate examiners and drivers. And now it is going from not doing it at all to doing so much. It is a shame that we are not doing it in 2023.

Researcher: Thank you for your time and with that I conclude this interview.

Interview 3

Researcher: Arav Kharkwal
Date: 21/06/2023
Location: Microsoft Teams [Online]
Semi-structured Interview with Driving Examiner

The interview began with the researcher reminding the participant (driving examiner) of the consent form and seeking their agreement for an audio recording of the interview. The subsequent conversation is transcribed below:

Researcher: I will begin by giving you a short summary of myself and my research. My name is Arav. I'm a second year, master student at TU Delft studying civil engineering. My degree is in transport and planning. I was connected to Daniel, and the R&D department by Dr. Marjan Hagenzieker, my advisor at TU Delft. The topic of road safety was interesting to me, and when I got to know more about what CBR is doing, I was really interested in this opportunity to research how ADAS can be introduced in the driving exam. Now if you could please tell me a little bit about yourself, your role at CBR and how long you've been a part of the organization?

Examiner 3: I have been working at CBR for about 30 years, mainly and mostly as a driving examiner for all categories except mopeds (category A). About 13 years ago I started working at product management, developing and maintaining all the driving test products. And for the last four years I have been working in the Research and Development department.

Researcher: Thank you for that. If I may ask, what inspired you to move from examining driving exams to product development?

Examiner 3: Well, that's two sided. Mainly education. I started university when I was 32-33 years ago. So, acting as an examiner, conducting 8 practical tests a day over the course of 10 years is a lot. So, I just swapped it for something that is more in-depth about the actions of the candidate or their driving behavior, and the development of the driving test. What kind of driving test procedure is the best. Thinking back to it, this was during the reorganization within CBR. There was a department called product management which was tasked with developing and maintaining the driving test. After a few years in that role, the team I worked in was completely gone, mainly outside CBR. So about three to four years ago, when I started at R&D, the team of product managers consisted of mainly young people. I then asked my manager is there anything I can do with all my experience and expertise? And R&D was a good fit for my experience.

Researcher: That's very interesting thank you. Going off of that, since I'm just inquisitive, how many examiners do you believe follow the same route as your in conducting driving exams and then moving to product development so maintain and develop the driving test further?

Examiner 3: Yeah well, I think it's more of my personality. Any experienced examiner can tell everyone they have experience in a lot of driving test. But I always ask is it the right way and the best way to test the younger people. And if I can't answer that questions, I look for the answer.

We investigate if current procedures are the right way forward, and if they are not, what can we improve.

Researcher: Well, thank you for that. Now I will now be sharing my screen to go over some things that will help give more context to the topics we will be discussing.

Researcher: This table by the SAE divided automation into six levels, from 0 to 5, with the degree to which automation takes over the driving task increasing at each level. Last year in June, the Mercedes-Benz driver pilot system was approved in Germany, making it the first Level 3 SAE system approved in the world. More recently, this has also been approved in a few states in the United States, namely California and Nevada. To summarize, only 2 Germany and USA currently have commercially available Level 3 systems for purchase. What makes this system Level 3 is that it has ability to continuously handle the driving task, while the driver can have their hands off the steering wheel, however, still be ready to take over the driving task when requested by the vehicle. Level 2 on the other hand, which is what Tesla's Autopilot is classified as, requires that the driver's hands be on the steering wheel when the system is active.

Researcher: I will now begin the interview by talking about ADAS specifically. My first question to you is "In your opinion, do drivers clearly understand how these ADAS function? If not, where do you think their understanding is lacking?"

Examiner 3: Well, the work understanding seems to be, on a scale from 0 to 10. Where there is a lack of understanding to use it in the right way. Understanding can mean that they use it in the right way, but it can also mean that using it in an alternative way that is not intended by the OEM's. Understanding also has to do with the kind of information you get. For example, if you are studying at university and you have a book that is focused on how people learn and what to learn. However, the manual of a car is just a technical explanation of what the systems can or cannot do. It is not specifically focused on how people learn. Mostly people don't even read the manual and find out by themselves. And it differs. People who read the manual only skim over it and read the minimum as to what is necessary to drive the car and use some of the accessories.

Researcher: Thank you. Lot of interesting points. With the first one being using something the way it is intended versus behavioral adaptations, anticipated or unanticipated. How people learn is also interesting, with there being so many stakeholders, for example dealerships. One of the things I learn from literature is that dealership also don't have the comprehensive knowledge to pass on to the consumers, and they do so only if they are asked. So, there is a mismatch. And how consumers compensate for that is trial and error like you said. Going from the driver's side to the examining side, my next question to you will be about the examiner side of things. My question is "How are the current driving tests addressing the use of ADAS? And is there an emphasis of these technologies?"

Examiner 3: I do not think it is at the moment. We have very little experience in testing the use of ADAS because in 2016 it was prohibited to use any system that was useful for the test candidates. In 2016 the prohibition was over and ADAS was allowed to be used without any

stipulations. And only now after the directives from Emy is it more a part of the driving test. But the problem with ADAS is that you use it, not use it, misuse it and abuse it. And then the next question is what kind of use you want to examiner, and if so, which standard would you develop to judge whether the use if sufficient or not sufficient. However, not using ADAS in a particular situation can also be optimal. So, we have to find this out. We have to find out in what way we can test the candidates and maybe generate a possible threshold or something similar.

Researcher: Do you think there is a need for candidates to be evaluated on their use or non-use of ADAS?

Examiner 3: From the point of view of the driving test, the candidate is free to use all the accessories in the car. A few years ago, we only had a four-gear changing box, after which came a five gear and six gear. So, if a candidate didn't use fifth or sixth gear, it was hard to tell whether the candidate was operating the car in the right way. So, we had to look for some other elements that are more measurable. So, we say, if you want to drive environmentally friendly, you have to use the highest possible gear, without telling them if that is the fourth, fifth, or sixth gear. And I think with ADAS, we have to look for similar applications. Why would you tell a candidate when you had to use a certain ADAS at that moment? I can't answer that now as it is relatively new in the practical driving test.

Researcher: Yes totally, and thank you for the insight. So I got that we still need to determine what to evaluate. I guess based on what we know now, with lot of us having experience in using ADAS while driving, which particular aspects need to be evaluated in the practical driving exam?

Examiner 3: Well, I think in the Dutch situation, you have to do the practical driving test in the car that is available from the driving school. I think that car is leading in what you can test and what you have to test. If some ADAS is not available, you can't test it. But if it's available, you have to evaluate what is the notch from the candidate, that is the starting point. And their skills to use or not use these systems while driving in the driving exam. And I think, which is a really personal opinion that "testing or evaluating ADAS as a separated part of the driving test is not the right way". The candidate has to mainly perform the driving test, and the is free to use all the available accessories to execute the driving task in the right way. So, a more holistic approach with how you drive in a modern car with the use of ADAS, but not specifically used ADAS yes or no, right way or not, with a certain amount of understanding etc.

Another way, that is only possible if you have a competency-based driving test, which we do, is that you still get a bill afterwards of how you drove at intersections and roundabouts. So, there is a discrepancy in what we want it to be, how it should be, and what it is now.

Researcher: Thank you. That's an interesting point to me too because how a driver operates a car is paramount. But there might also be a situation where somebody uses ADAS and gets evaluated on that and fails the whole exam, while another candidate does not use ADAS and passes the whole exam. Along with the test variability like time of day, roads, traffic etc. Now

that we've spoken about how to incorporate ADAS in the driving exam, the challenges that come along with that, I would like to discuss my developed matrix for examiners with you.

----------Part 2: ADAS Matrix----------

I will now share my screen with you to show you what I have developed to help examiners evaluate candidates. The process was as such: I compiled the ADAS in the market currently and divided them into whether they take-over the driving task at any time or help the driver in making decisions that could help avoid hazard. So, as you mentioned automatic parallel parking earlier, it was not selected by me as well as it does not exhibit operational knowledge of parking a car. Although the driver still has to monitor this maneuver that is undertaken by the systems in the car. After selecting the ADAS, I started to shortlist behaviors that drivers need to demonstrate to prove to the examiners their proficiency or lack of it with the ADAS available in the car. I will give you a few minutes to go over this and then we could discuss it more.

After 2 minutes

Researcher: As our scheduled field experiment was not able to take place due to the unavailability of a car, I will ask some of the questions in this interview that I planned to during the field experiment. The first question is on the interpretation of the field. On a scale of 1 to 5, with 1 being very easy and 5 being very difficult, how would you rate the interpretation of the titles of the fields for each column.

Examiner 3: Proceeds to rate all fields.

Researcher: Now I'd like to move on to "how important is it to exhibit these behaviors for safe operation of a modern vehicle, particularly during a driving exam"?

Examiner 3: Proceeds to rate all fields.

Researcher: Well, thank you for that and your insights. My idea with the matrix was that I basically tried to combine all things which were considered safety critical from literature, where either the technology is lacking in terms of how important it is, or the understanding of the driver is lacking. Looking at this matrix, what do you think are its strengths and weaknesses?

Examiner 3: Well, there are always weaknesses. Looking at the strength, for instance "no secondary activities while driving" has an educational value if used in the practical test. The driving instructors will teach the students to always be aware of the situation you're in and do not undertake another activity while driving the car. So, it has value from an educational point of view for all the fields. The weakness for the practical driving tests is the measurability of all the constructs, like I mentioned situational awareness already. Also, reacting to and expected and unexpected take-over and when it is sufficient to do so. But the threshold is missing. It is important but very difficult to standardize and even measure in this case. The interpretation being important. There being 600 driving examiners, they would need to interpret it a certain way and reach the same verdict for the varying situations observed for various candidates. And

they have to be exactly the same to give the same conclusions about their observations. So, calling it a weakness is not fair as it suggest it's not sufficient or something else. It is not weak but difficult.

----------Part 3----------

Researcher: Thank you for that. And that makes me think of another interesting point which is the existing CBR matrix. I think my matrix serves as a stepping point to integrating ADAS more comprehensively and efficiently in a driving exam. What I envision is that some fields that cannot be clearly interpreted just from text will need to be described in more detail in the driving procedure. It may still leave room for interpretation but it is still a way to decipher these fields and make it more condensed to reduce the workload of the examiner. My question to you is, "Should the ADAS guidelines currently listed in the driving procedure, be more in-depth?"

Examiner 3: Our driving procedure at this moment is already 30 to 40 years of age. Will that be the document you have to use with the changing competencies for ADAS etc.? I have many doubts about this. You have to modernize the system. Modernization also sees the used terms; I already said you can use the work adequately. But when is just adequate or not adequate enough will always be very difficult. But sometimes you have to look to the future, not only the weaknesses that are in the past, and more importantly how to address these weaknesses. So, my main takeaway is to look to the future and not dwell on the past.

Researcher: So just for my knowledge, is there any talk at CBR to modernize the driving test or the driving procedure as you say?

Examiner 3: No, not at all. We have a project "Data driven examination". I had a meeting with TNO this week, the scientific research organization. And even in that, they are currently looking to find data points in the existing driving procedure. My opinion, very personal, is that it is a waste of money to look for solutions in a very old document. Look to the future.

Researcher: So how exactly are they trying to do that, and what's their approach?

Examiner 3: It was my first time being confronted with that information and that meets your question. I only saw some images just driving the route, and measuring the G forces a drivers is subject to, giving the acceleration and deceleration. And based on this they plan to say this is done right and this is not done right. During the meeting I gave an example of approaching an intersection with a lot of trees etc. During the summer you can't look much to the left or right, but during the winter your speed can be a little bit higher because there are no leaves on the trees. So, the measurability of only speed may not be sufficient. Answering your question, it is difficult for me to describe what they want to measure and the thresholds for that.

Researcher: That's very interesting because one thing I learnt a lot on the rides is that the subjective judgement of the examiner is crucial, and putting in thresholds to that complicates that even further.

Examiner 3: Well, I think that a lot of examiners have the opinion that they are giving a verdict on “whether you are a good driver”. However, I believe it should be more like giving a prediction that “I think the candidate will develop into a good driver.” And I think that could also be the case for ADAS in regard to using it correctly. It has to be consistent with many data points for the examiners. The examiner does not give any more information than a prediction that the candidate will develop into a good driver.

Researcher: Thank you for that. It is something I also have to keep reminding myself in this research that examiners are not judging how good somebody is at driving, rather, they are passing a verdict on whether the candidate drivers at a level that they can develop their skills on the road after passing the practical driving exam. My next question to you will be on preparing examiners for the future. My question is “What kind of preparation or training might be necessary for examiners?”.

Examiner 3: Well, I think all the concepts that are used for the construction of ADAS, even artificial intelligence and algorithms, and that there should be a knowledge base for CBR and the examiners from which they transition from traditional use of gasoline and gearbox to more “Information and Communication Technology” (ICT) minded knowledge. The development of ADAS is the first step to automated driving systems (ADS) and examiners should have a basic knowledge of what a car consists of nowadays, electricity, Lidar, ADAS, radar etc. So more technical knowledge.

Researcher: To you knowledge, is that covered in the current training procedures for examiners?

Examiner 3: No, not currently. Unless the teacher takes a special interest or the examiner training has intrinsic motivation to gain the said knowledge.

Researcher: Thank you for that. My next question is from the point of a driver. Say I am a young driver and I do not want to be forced to use something like this. My question is “what impact do you anticipate a forced ADAS demonstration having on young drivers?”

Examiner 3: Well, it’s not like the mind of youth is changing, it is always the same, but the mindset is changing. On one hand they want to know everything about iPhone and gaming but compulsory elements to gain knowledge of skills, they are not in favor of that. Because you can ask them but not force them. But it is general knowledge that during the development of the mind, youths are more likely to be more thrill-seeking, and it will continue to be an issue.

Researcher: Thank you for that, and I can attest to that because I observed the same during the field experiment where me and the participants were fascinated by the technology so much that we wanted to put to test all the technology equipped in the car. My next question for you is related to policymaking and driving schools. My question is “What role do you anticipate driving schools to play if ADAS is planned to be introduced in the driving exam?”

Examiner 3: Well, you can discuss how to test ADAS in the practical exam, but the main issue is what is in the driving test so that the driving examiner gives attention to this phenomenon. If

you don’t put it in the driving test, there will be no attention at all. So, it is more important that the education at this point is of a very high level because you can’t test everything in the driving test. So, it’s just a little finger pointing from CBR to the driving instructors saying give attention to all what we want to test. If it is not possible in just one single 35-minute test, you still have to teach new students all that is possible.

But, in the Netherlands the average of driving lessons is about 40 hours and if it is increased to 50 or 60 even, which is normal in my point of view, then there will be lot of reluctance because they will have to pay. And if the policymakers think that the driving test will become expensive to the point that a part of the Dutch population can’t pay that, then they won’t be making any rules for it.

Researcher: That’s very interesting that one of the biggest stakeholders in this topic changes every four year and decides where the money goes. My last question is “With there being so many stakeholders in this process and the recent news that came out that ADAS is not going to be in the driving test next year, do you anticipate a rough timeline by when ADAS might be implemented into the exam?”

Examiner 3: Well, I think no matter at what moment it is implemented in the driving test, it being implemented will be a victory in itself.

Researcher: Thank you for that. Which is why I feel like it's a great opportunity for me to be able to do this with CBR and for the future as well. With that, I conclude this interview. Thank you so much for your time today. Is there anything else you would like to discuss today? Any questions or comments you may have on my research?

Examiner 3: No, not at the moment.

Researcher: Thank you so much for your time again. I really enjoyed this conversation with you and I got a lot of a lot of insight. I hope you have a good rest of your week.

Examiner 3: Thank you, you as well.

Appendix C – Thematic Analysis of Interviews

Step	Description/Details
1. Familiarization with Data (Initial Observations)	• Varied stakeholder perspectives on the integration of ADAS in driving exams. • Recognized benefits and potential drawbacks or concerns related to ADAS. • Changing dynamics in driver assessment methodologies with the advent of ADAS. • Evolution in driver education and training approaches due to ADAS. • The increasing emphasis on examiner training and readiness for ADAS-driven changes. • Discussions surrounding the practicalities and challenges of ADAS policy implementation. • The pace and nature of policy adaptations in response to ADAS innovations.
2. Generating Initial Codes	• Stakeholders' perceptions of ADAS • Benefits and challenges of ADAS • Changes in driver assessment due to ADAS • Changes in driver education due to ADAS • The evolving role of examiners • Necessities for examiner training regarding ADAS • Practical implications of ADAS policy • Dynamics between stakeholders in the context of ADAS implementation • The pace at which policies regarding ADAS are changing
3. Searching for Themes	i. Adaptation ADAS: Stakeholders' perceptions and adaptations to the new technology. ii. Steps for the Future: The changing dynamics of driver assessment and education in the context of ADAS. iii. Examiner Training and Skill Development: Necessity for updating and aligning examiner capabilities with ADAS evaluations. iv. Policy and Implementation: The challenges and practical aspects of integrating ADAS into driving exams.
4. Reviewing Themes and sub-themes	i. Adaptation to ADAS: Benefits and Advantages, Challenges and Limitations, Youth's Approach, Examiners' Perspective. ii. Steps for the future: Driver Assessment, Driver Education, Role of Examiners. iii. Examiner Training and Skill Development: ADAS Education, ADAS Skill Development, Training Alignment. iv. Policy and Implementation: Financial implications, Stakeholder dynamics, Pace of policy change

5. Defining and Naming Themes	i. Adapting to ADAS: Readiness, acceptance, and reservations towards ADAS. ii. Preparing for the future: Effects of ADAS on traditional roles. iii. Examiner Training and Skill Development: Updating education and skills for ADAS evaluations. iv. Policy and Implementation: Practicalities, challenges, and strategies for ADAS implementation.
6. Reporting the results	Results have been reported in Chapter 4 (Section 4.5)

Appendix D – Consent Forms

Case Study 1

Introducing ADAS Evaluation into a Driving Exam

Consent Form for participants of Pilot Study

You have been requested to participate in a research pilot study conducted by TU Delft, Faculty of Civil Engineering and Geosciences, department of Transport & Planning, in collaboration with CBR, as a part of a master's thesis.

Introduction

The research study aims to develop a method for examiners to evaluate drivers' understanding, knowledge, and ability to use ADAS during a practical driving exam in the Netherlands. The experiment is conducted by TU Delft, in cooperation with CBR. Your participation in this study will be in the form of an examiner using a developed assessment matrix for a list of ADAS. 6 driver behaviors have been highlighted based on CBR guidelines in the Rijprocedure B (2023) and the latest research.

Procedure

Regular assessment procedures will be conducted per the guidelines in Rijprocedure B (2023). The researcher will preview the matrix with the examiner and clarify any doubts before the mock practical driving test with a candidate. The candidate will be a non-participant in this research. The ADAS systems that will be evaluated, along with a short description, are as follows:

- Lane Keeping Assist (*LKA*): Automatically adjusts steering to keep the vehicle centered in its lane
- Lane Departure Warning (*LDW*): Alerts the driver when the vehicle drifts out of its lane.
- Forward Collision Warning (*FCW*): Warns the driver of potential front-end collisions
- Advisory Max Speed Limit: Displays real-time speed limit information based on GPS data and sign recognition and usually warns the driver in some form.
- Cruise Control : Maintains a constant vehicle speed set by the driver
- Adaptive Cruise Control (*ACC*): Adjusts vehicle speed to maintain a safe distance from the car ahead.
- Automatic Emergency Braking (*AEB*): Applies brakes automatically to prevent or mitigate collisions.

Upon completion of the driving exam, the ADAS matrix will need to be evaluated with the same intentions as the CBR evaluation matrix. A copy of the CBR evaluation matrix will also be taken to analyze any possible overlaps in the developed matrix.

Following this, a short questionnaire gathering the experience of the examiners during the experiment and feedback on using the matrix will be handed out. Responses to this questionnaire are considered essential to current and future research in this field.

Risks

The risks associated with this study are minimal and comparable to your usual job duties. To address the concerns of heightened workload and potential distraction, an easy-to-use matrix has been developed. We are not responsible for any traffic accidents that may occur. Privacy safeguards have been implemented to protect participant data. You are encouraged to discuss any issues or discomfort with the researcher throughout the experiment.

Data Collection

The data collected during the experiment will be in the form of voice recordings, input for developed ADAS evaluation matrix, input for CBR evaluation matrix, and a questionnaire. The purpose of this data and its management plan has been described on the next page.

Table 21 - Data Collection Items, Purpose, and Management Plan

Data Collection Item	*Purpose*	*Data Management Plan*
Voice Recording	To get more context from the experiment and understand the working of a practical driving exam.	Anonymize and securely store data. Restrict access to authorized researchers. Transcribed to text and deleted. Analyze and report in aggregate. Adhere to TU Delft Guidelines and privacy regulations.
Input for ADAS Matrix	Research methodology being tested	Anonymize and securely store data. Restrict access to authorized researchers. Analyze and report in aggregate. Adhere to TU Delft Guidelines and privacy regulations.
Input for CBR Matrix	To ensure efficacy of ADAS Matrix by cross-checking for overlaps with the CBR Matrix	Same as above
Questionnaire	Gather experience during field experiment and feedback on ADAS matrix.	Same as above

Voice Recording

By participating in this study, you consent to the recording of your voice during the ride. The recordings will be transcribed to text and used solely for the purpose of accurately capturing your responses and understanding your experiences. The recordings will be kept confidential, stored securely, and deleted after use. Your participation in this aspect of the study is voluntary and will not affect your eligibility to participate in the study overall. If you wish to not participate in this part of the research, please put an X on this section and/or inform the researcher.

Participation, withdrawal, and your data

- Your participation of this study is completely voluntary.
- You have the right to withdraw from the experiment at any time without an explanation or any negative consequences.
- You may refuse to answer any questions that you do not wish to answer.
- You have the right to receive a copy of your data.
- The collected data will be securely stored in the project storage drive and OneDrive on the TU Delft servers. Only the researcher will have access to this data
- You possess the right to ask for partial or total deletion of your data from the dataset. Upon your request, your data will be eliminated, excluded from the analysis, and not incorporated into the final outcomes.
    - Please note that the results will not contain any personally identifiable information.
    - Please note that, within a week of data collection, no identifiable information remains in the dataset, rendering it impossible to determine which data belongs to you.

Further Questions

For any further questions please contact any of the researchers.

Researchers

MSc student: Arav Kharkwal (a.kharkwal@student.tudelft.nl)

Supervisors: dr. Daniël D. Heikoop (daniel.heikoop@cbr.nl) , dr. Sina Nordhoff (s.nordhoff@tudelft.nl), dr. ir. Simeon Calvert (s.c.calvert@tudelft.nl), dr. Marjan Hagenzieker (m.p.hagenzieker@tudelft.nl)

I have read and understand the information provided above. My questions have been answered to my satisfaction. I have been given a copy of this form and I agree to participate in this study.

Name of Participant: _____

Signature:

Date:

I, as a researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting

Name of researcher: _____

Signature:

Date:

Interview

Introducing ADAS Evaluation into a Driving Exam

Consent Form for participants of Research Interview

You have been requested to participate in a research interview conducted by TU Delft, Faculty of Civil Engineering and Geosciences, department of Transport & Planning, in collaboration with CBR, as a part of a master's thesis.

Introduction

The research study aims to develop a method for examiners to evaluate drivers' understanding, knowledge, and ability to use ADAS during a practical driving exam in the Netherlands. The interview is conducted by TU Delft, in cooperation with CBR. Your participation in this study will be in the form of an interview where you provide feedback and insights on a developed assessment matrix for a list of ADAS.

Procedure

The interview will last for approximately 30-40 minutes. It will begin with the researcher introducing the developed assessment matrix and a brief overview of each ADAS system that was evaluated. You will then be asked to provide your feedback, experiences, and suggestions related to the assessment matrix and the ADAS systems based on a semi-structured interview guide that the researcher will follow. The ADAS systems evaluated, along with a short description, are as follows:

- Lane Keeping Assist (*LKA*): Automatically adjusts steering to keep the vehicle centered in its lane
- Lane Departure Warning (*LDW*): Alerts the driver when the vehicle drifts out of its lane.
- Forward Collision Warning (*FCW*): Warns the driver of potential front-end collisions
- Advisory Max Speed Limit: Displays real-time speed limit information based on GPS data and sign recognition and usually warns the driver in some form.

- Cruise Control : Maintains a constant vehicle speed set by the driver
- Adaptive Cruise Control (*ACC*): Adjusts vehicle speed to maintain a safe distance from the car ahead.
- Automatic Emergency Braking (*AEB*): Applies brakes automatically to prevent or mitigate collisions.

Risks:

The risks associated with participating in this interview are minimal and mainly involve sharing your personal opinions and experiences related to ADAS and its introduction into practical driving exams. There is a possibility that you may feel uncomfortable discussing certain topics, especially if they involve sensitive information or potential weaknesses in the examination process. However, we assure you that all information shared will be treated confidentially and that you have the right to refrain from answering any questions that you find uncomfortable or inappropriate. Additionally, any information provided will be anonymized during data analysis and reporting, ensuring that your identity remains protected.

Data Collection:

The data collected during the experiment will be in the form of voice recordings. The use for this data and procedure for its management has been described in Table 1.

Table 22 - Data Collection Items, Purpose, and Management Plan

Data Collection Item	*Purpose*	*Data Management Plan*
Voice Recording	To ensure verbatim capturing of the participants' insights and experiences.	Anonymize and securely store data. Restrict access to authorized researchers. Transcribed to text and deleted. Analyze and report in aggregate. Adhere to TU Delft Guidelines and privacy regulations.
Questionnaire (gender, age group, experience, education, training, and job details)	To gather diverse perspectives and insights on the challenges, potential impacts, and recommendations related to incorporating ADAS evaluation into practical driving exams. Also, for comparison of metrics across participants.	Anonymize and securely store data. Restrict access to authorized researchers. Analyze and report in aggregate. Adhere to TU Delft Guidelines and privacy regulations.

Participation, withdrawal, and your data

- Your participation of this study is completely voluntary.
- You have the right to withdraw from the experiment at any time without an explanation or any negative consequences.
- You may refuse to answer any questions that you do not wish to answer.
- You have the right to receive a copy of your transcript.
- The collected data will be securely stored in the project storage drive and OneDrive on the TU Delft servers. Only the researcher will have access to this data
- You possess the right to ask for partial or total deletion of your data from the dataset. Upon your request, your data will be eliminated, excluded from the analysis, and not incorporated into the final outcomes.
    - Please note that the results will not contain any personally identifiable information.
    - Please note that, within a week of data collection, no identifiable information remains in the dataset, rendering it impossible to determine which data belongs to you.

Further Questions

For any further questions please contact any of the researchers.

Researchers

MSc student: Arav Kharkwal (a.kharkwal@student.tudelft.nl)

Supervisors: dr. Daniël D. Heikoop (daniel.heikoop@cbr.nl) , dr. Sina Nordhoff (s.nordhoff@tudelft.nl), dr. ir. Simeon Calvert (s.c.calvert@tudelft.nl), dr. Marjan Hagenzieker (m.p.hagenzieker@tudelft.nl)

I have read and understand the information provided above. My questions have been answered to my satisfaction. I have been given a copy of this form and I agree to participate in this study.

Name of Participant: _____

Signature:

Date:

I, as a researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting

Name of researcher: _____

Signature:

Date:

Case Study 2

Introducing ADAS Evaluation into a Driving Exam

Consent Form for participants of Field Experiment

You have been requested to participate in a research experiment conducted by TU Delft, Faculty of Civil Engineering and Geosciences, department of Transport & Planning, in collaboration with CBR, as a part of a master's thesis.

Introduction

The research study aims to develop a method for examiners to evaluate drivers' understanding, knowledge, and ability to use ADAS during a practical driving exam in the Netherlands. The experiment is conducted by TU Delft, in cooperation with CBR. Your participation in this study will be in the form of an examiner using a developed assessment matrix for a list of ADAS. 6 driver behaviors have been highlighted based on CBR guidelines in the Rijprocedure B (2023) and the latest research.

Procedure

The researcher will preview the matrix with you and clarify any doubts before the mock practical driving exam. Your role as an examiner will be to evaluate the candidate driving the car based on regular assessment procedures described in Rijprocedure B. The ride will also be conducted per guidelines in Rijprocedure B. The candidate/driver is a non-participant in this research. The ADAS systems which the matrix aims to evaluate are as follows:

- Lane Keeping Assist (*LKA*): Automatically adjusts steering to keep the vehicle centered in its lane
- Lane Departure Warning (*LDW*): Alerts the driver when the vehicle drifts out of its lane.
- Forward Collision Warning (*FCW*): Warns the driver of potential front-end collisions
- Advisory Max Speed Limit: Displays real-time speed limit information based on GPS data and sign recognition and usually warns the driver in some form.
- Cruise Control : Maintains a constant vehicle speed set by the driver
- Adaptive Cruise Control (*ACC*): Adjusts vehicle speed to maintain a safe distance from the car ahead.
- Automatic Emergency Braking (*AEB*): Applies brakes automatically to prevent or mitigate collisions.

Upon completion of the driving exam, the ADAS matrix will need to be evaluated with the same intentions as the CBR evaluation matrix. A copy of the CBR evaluation matrix will also be taken to analyze any possible overlaps in the developed matrix.

Following this, a short questionnaire gathering the experience of the examiners during the experiment and feedback on using the matrix will be handed out. Your responses to this questionnaire are considered essential to current and future research in this field.

Risks:

The risks associated with this study are minimal and comparable to your usual job duties. To address the concerns of heightened workload and potential distraction, an easy-to-use matrix has been developed. We are not responsible for any traffic accidents that may occur. Privacy safeguards have been implemented to protect participant data. You are encouraged to discuss any issues or discomfort with the researcher throughout the experiment.

Data Collection:

The data collected during the experiment will be in the form of input for developed ADAS evaluation matrix, input for CBR evaluation matrix, and a questionnaire. The use for this data and procedure for its management has been described in Table 1.

Table 23 - Data Collection Items, Purpose, and Management Plan

Data Collection Item	*Purpose*	*Data Management Plan*
Input for ADAS Matrix	Evaluate the effectiveness and applicability of the developed ADAS assessment matrix during practical driving exams	Anonymize and securely store data. Restrict access to authorized researchers. Analyze and report in aggregate. Adhere to TU Delft Guidelines and privacy regulations.
Input for CBR Matrix	Compare and validate the developed ADAS assessment matrix against the existing CBR evaluation matrix for consistency and potential overlaps	Same as above
Questionnaire (gender, age group, experience, education, training, and job details)	Gather experience during field experiment and feedback on ADAS matrix. Comparison of metrics across participants.	Same as above

Participation, withdrawal, and your data:

- Your participation of this study is completely voluntary.

- You have the right to withdraw from the experiment at any time without an explanation or any negative consequences.
- You may refuse to answer any questions that you do not wish to answer.
- You have the right to receive a copy of your data.
- The collected data will be securely stored in the project storage drive and OneDrive on the TU Delft servers. Only the researcher will have access to this data
- You possess the right to ask for partial or total deletion of your data from the dataset. Upon your request, your data will be eliminated, excluded from the analysis, and not incorporated into the final outcomes.
    - Please note that the results will not contain any personally identifiable information.
    - Please note that, within a week of data collection, no identifiable information remains in the dataset, rendering it impossible to determine which data belongs to you.

Further Questions

For any further questions please contact any of the researchers.

Researchers

MSc student: Arav Kharkwal

Supervisors: dr. Daniël D. Heikoop , dr. Sina Nordhoff
dr. ir. Simeon Calvert,
dr. Marjan Hagenzieker

I have read and understand the information provided above. My questions have been answered to my satisfaction. I have been given a copy of this form and I agree to participate in this study.

Name of Participant: _____

Signature:

Date:

I, as a researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting

Name of researcher: _____

Signature:

Date: