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ScienceDirect

Procedia CIRP 93 (2020) 1286–1291

www.elsevier.com/locate/procedia

53rd CIRP Conference on Manufacturing Systems

Naturalistic driving study for Automated Driver Assistance Systems (ADAS) evaluation in the Chinese, Swedish and American markets.

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Abstract

In recent years, Automated Driver Assistance Systems (ADAS) have received great promotion and acceptance in the European market. However, transferring ADAS to other markets may affect driver behavior due to the cultural and contextual differences in various markets. Methods used for capturing these differences are based on subjective data collection. This study shows how vehicle data collected in the ND study helps to identify and investigate further the differences in driver behavior and the driving context in the Chinese, Swedish and US markets. This paper discusses a better way to consider the infrastructural and cultural differences in ADAS design.

Keywords:ND study; vehicle data; data-driven evaluation; ADAS; markets analysis

1. Introduction

In recent years, Automated Driver Assistance Systems (ADAS) have received great promotion and acceptance in the European market. ADAS are systems designed to assist the driver in various driving tasks. ADAS range from different types of information and warning systems to adaptive functions that offer longitudinal control of the vehicle through accelerating or braking in various traffic conditions, and/or lateral control through providing steering assistance [1]. Adaptive Cruise Control (ACC) and Pilot Assist (PA) are examples of ADAS functions. ACC is a function that, with the help of vehicle cameras and radar system, helps the driver automatically by adjusting the vehicle's speed with regard to other objects moving in front, considering preselected speed and the time interval to the vehicle in front. PA adds to the ACC longitudinal support in the lateral control of the vehicle, providing the ability to keep the car in the road lane [2].

Most of the automotive companies provide ADAS among the available options in newly produced vehicles. Drivers have familiarized themselves with the level of automation and support current systems offer. Our previous study on driver behavior evaluation of ADAS in the Swedish/European market [3] indicated that most drivers are able to interact and cope with the automation provided, with a use level of the ACC function equivalent to 24.5% and for PA 9.5% of total driving activities. Further, the results show that the driving context plays a significant role in driver interaction with the ADAS. The driving context affects ADAS usage through system performance, indicating that the limitations of the ADAS design influence the driver's trust and willingness to use the systems over the long term. Moreover, the driving context directly affects the real-time decisions of the driver regarding the activation and deactivation of the ADAS functions.

Thus, transferring the ADAS technology to another context needs to be done with consideration of driver context differences. The system needs to be adapted to the market

10.1016/j.procir.2020.04.108

where it is intended to be used. Lindgren et al. [4] suggest that system functionality and system support be adapted to the driving conditions in the new market and consider the cultural differences that, according to the results provided by Lee and Seppelt [5], affect driver behavior and play a critical role in driving safety.

Various methods are currently used to evaluate ADAS across markets. Some methods are focused on capturing cultural differences affecting driver behavior with ADAS (such as lane change behavior, using the phone while driving, active/passive driving, etc.). Other methods attempt to assess the differences in road infrastructure, traffic density, and traffic information design across markets, trying to understand the effect of driving context on driver behavior and the use level of ADAS. Chen et al. [6] evaluated the HMI design of ADAS in the Chinese market and pointed out that no adaptive design to ADAS functions was usually implemented. The ADAS HMI was typically only translated to the Chinese language without any attempt to consider the mental model of Chinese drivers or apparent differences in the driving context. Similar results were achieved while evaluating the HMI design adaptation between the Australian and Chinese markets [7]. Jeon et al. [8], with the help of a survey, assessed cross-cultural differences between the Austria, USA and South Korea, identifying the different attitudes towards in-vehicle technologies across these markets. Zhang et al. [9] empirically investigated driver behavior by conducting a direct field observation in the Chinese market. Nirschl [10], using the driver simulation system, designed a method to measure the potential impact of ADAS usage on traffic safety. The study of An et al. [11] designed a framework for ADAS evaluation using multi-source data collection, focusing on safety, driver efficiency, driver acceptance and the operation cost of ADAS.

However, the majority of methods used for ADAS evaluation across markets are based on subjective data collection in the form of interviews with drivers, surveys, observations, and studies with strict experimental design conducted through drive simulations or driving conducted in a closed testing site.

Our goal in this study is to show how vehicle data collected in the ND study can be used for ADAS evaluation in different markets in the real driving environment. The ultimate goal is to identify and understand the main differences in driver behavior and the driving context in three different markets, as well as to discuss a better way to consider the infrastructural and cultural differences in various markets with regard to ADAS design. In this paper we describe a study evaluating ADAS use in the Chinese (CN), Swedish (SE) and USA (US) markets, to understand the key differences in driving context and driver behavior across different markets.

2. Method

In the course of this study, performance data for both the driver and system were measured together with contextual information indicating the speed, type of driving activities, weather conditions, GPS location, and other information.

The ND data in this study enabled time-efficient and reliable objective evaluation of ADAS usage in three different markets, in combination with system and driver performance. The data analysis was carried out with a focus on the defined objectives and questions formulated beforehand. The level of usage and the differences in ACC & PA use in different markets, and the identification of various trends in driver use patterns was addressed.

The data in this study was collected with the informed consent of all drivers and their prior agreement to participate in the ND study. The retrieval, storage and processing of the collected data was accomplished strictly according to the European general data protection regulations (GDPR). The data was processed confidentially, and all participant identities were kept strictly anonymous.

2.1. Participants

Drivers of 218 vehicles participated in this study. All participants were Volvo Cars employees who bought and used the vehicle as a primary source of transportation for the full range of activities, including their commute to work, weekend trips, vacation, and all other possible driving activities. Most of the study participants were the only drivers of their vehicles. However, the possibility to share the vehicle with family members or friends existed and was not controlled. Since, in this study, we were primarily focused on differences in use scenarios across different markets, the particular drivers' contribution was not a focus of this investigation.

Moreover, previous driver experience and the time drivers needed to familiarize themselves with the ADAS functions were not considered. We deliberately invited drivers with different levels of expertise regarding ADAS functions, trying to replicate the real situation in the respective markets. According to our setup, all drivers were given three weeks of introductory driving where they could use vehicles freely, try new systems, and become familiar with the functions before the measuring process started.

2.2. Study design and procedure

In the course of this study, data from 218 vehicles (SE market – 143 vehicles, US market – 14 vehicles, CH market – 61 vehicles) was collected and subsequently analyzed. Drivers were not limited to a geographical area of driving. For example, the SE market includes trips within Europe, with the majority of these being in Nordic countries. All evaluated vehicles had the same version of the ACC and PA installed on seven Volvo car models. Vehicles were chosen and preordered by the study participants.

Driver behavior and system performance was measured to be able to evaluate these separately and identify their effects on each other. Data variables that enabled the understanding of ADAS usage, (e.g., vehicle speed, driving distance, type of driving activity, date of the event, time of the day the activity happened, etc.) helped to recognize the use scenarios that characterize every geographical market.

Data variables that enabled the understanding of the driving context for ADAS were also included in the assessment, e.g., GPS data, wiper sensors status, data for road conditions identification, data indicated traffic conditions, and other sensors data. The analysis of this data supported the possibility to conclude the context in which the driver performed activations or deactivations of the ADAS functions.

2.3. Data retrieval and data pre-processing

The data collection was conducted using the WICE system. The WICE system is an external wireless communication and data acquisition unit that was installed in every test vehicle. The WICE system enabled the management of the data from the vehicle fleet, by keeping track of map-based positioning, mileage, uptime and diagnostic codes.

The raw data consisted of data from the Controller Area Network and the GPS data and was collected for every Drive Cycle (DC). By single DC we mean one driving activity that starts with the turn-on of the ignition and ends when the ignition turns off. All DCs, including DCs with no data, were included in the evaluation. Every DC was recorded and documented with a unique file name to be able to connect the vehicle to its data and conduct evaluation later.

In the data pre-processing step, all corrupt and inaccurate records were removed from the dataset. The data was synchronized in time, providing the order and structure for the initial dataset. The data collection phase for this study was conducted over seven months, from April to October 2018.

2.4. Data analysis

In total, 101,681 DCs were analyzed, where 67,652 were DCs in the SE market, 6,619 DCs were in the US market, and 27,410 DCs were in the CH market.

For the main phase of the quantitative analysis, a confirmatory approach was adopted with the aim of clarifying the differences in the usage of ADAS functions across the three different markets. The data analysis was conducted with Power BI software for statistical analysis [12], applying three different layers of abstraction: groups comparison layer (based on the comparison of ADAS functions usage across different markets), one-driver evaluation layer (focused on in-depth use scenarios analysis of the same driver), and single DC evaluation layer (if something indicated unusual or exceptional use strategy in a specific DC that needed in-depth investigation).

3. Findings

In this section, the main findings from the vehicle data analysis are presented. Findings focused on ADAS systems usage in three different markets and on the investigation of the differences among the ADAS use behavior across markets.

Finding 1: *The usage level of ACC and PA functions varied significantly in the three investigated markets.*

In the first step we measured how ACC and PA were used by drivers in the three different markets. Averages for PA and ACC use were calculated based on seven months of measuring. Fig. 1 graphically represents finding 1, measuring if at least one activation of ACC and PA was done during a single DC.

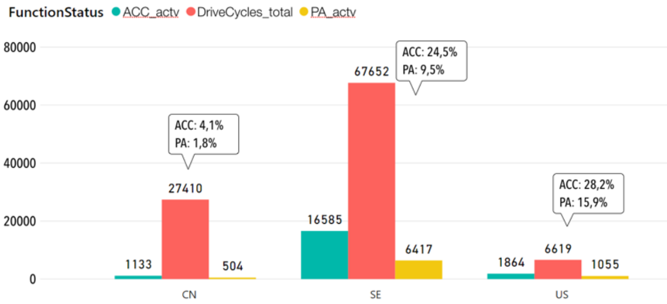

Fig. 1. Comparison of average use of ADAS functions in the CN, SE and US markets.

As Fig. 1 reveals, the average use level of both functions is higher in the US market (ACC: 28.2% and PA: 15.9%). The SE market shows slightly lower use of ACC (24.5%) and almost a 50% lower use of PA (R=9.5%) compared to the US market. The use level of functions in the CN market is uncomparably low, amounting to 4.1% for ACC and 1,8% for PA, respectively.

It is essential to mention that the monthly distribution of the ACC and PA activations did not change dramatically, deviatong only a little from average values on each market during all months of the measuring period, which is shown in Table 1.

Table 1. Monthly average of ACC and PA functions usage in the CN, SE and US markets.

	CN market		SE market		US market	
	ACC	PA	ACC	PA	ACC	PA
April'18	5.5%	2.5%	26.6%	9.0%	43.5%	19.6%
May'18	4.1%	2.1%	25.4%	9.6%	35.1%	18.7%
June'18	4.1%	2.5%	25.6%	9.0%	32.4%	18.4%
July'18	2.3%	2.0%	26.5%	8.3%	29.3%	13.2%
August'18	3.7%	2.1%	22.1%	8.2%	21.6%	13.1%
September'18	3.9%	1.5%	23.0%	10.1%	23.3%	14.6%
October'18	4.5%	1.5%	23.8%	10.4%	30.3%	17.9%

However, the average use of functions where at least one activation in a single DC is considered as 100% of usage does not always represent the real usage scenario. The number of activations within a single DC can differ significantly between two similar DCs and is highly dependent on driving conditions for the particular driving situation [3]. Therefore, the ratio, as a measure of the total amount of activations of ACC and PA to the total amount of DCs, was measured in three different markets (see Fig. 2).

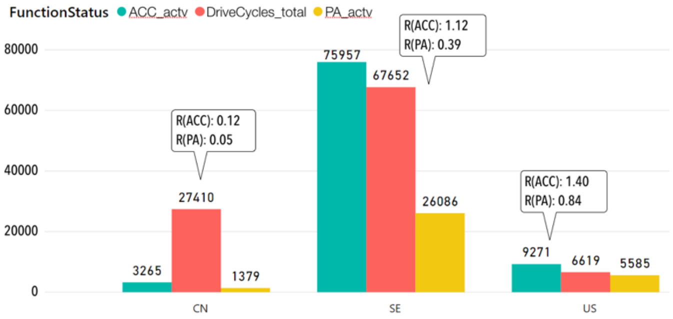

Fig. 2. Complete amount of ACC and PA in relation to the total amount of DCs in the CN, SE and US markets.

As Fig. 2 shows, the calculated ratio does not contradict the previously calculated average. The use ratio is higher in the US market than in the SE and CN markets, reaching 1.40 for ACC and 0.84 for PA usage. Swedish market shows slightly lower use of ACC (R=1.12) and almost half lower use of PA (R=0.39) compared to the US market. The use of ACC and PA in the CN market remains consistently low, amounting to 0.12 for ACC and 0.05 for PA, respectively.

A cross-market comparison of the driving activities where the systems were activated reveals that users in the CN market are less active within one single DC. They perform on average 2.8 activations of each ADAS function per DC, while drivers in the SE market perform 4.4 activations on average and drivers in the US market perform on average 5.1 activations of each ADAS function per DC.

The level of activity within a signal DC can indicate a difference in driving context that does not allow drivers to activate functions more often. The road structure or traffic conditions may bring some constrains and affect the drivers' decision to activate functions more often.

Finding 2: *Drivers from the US market use PA more often in longer DCs, while drivers from the SE market use PA more effectively in short DCs.*

One of the parameters, identified in [3] as the parameter that has a high impact on the use of ADAS functions, is the type of driving activity. Usually, drivers more commonly use automation when the driving activity is longer. However, based on the DC types distribution on the three investigated markets, the difference between long, medium and short DCs is not significant (see Table 2):

Table 2. DC types distribution in the CN, SE and US markets.

	Short DC (DC≤15 km)	Medium DC (15<DC≤50 km)	Long DC (DC≥50 km)
CN market	69.2%	22.0%	8.8%
SE market	73.8%	19.7%	6.6%
US market	64.0%	17.7%	18.3%

Despite the apparent correlation between long driving activities and higher use of the ADAS functions in long DCs in the US market, the same relation is not valid for the SE and CN markets. In the SE and CN markets, DC types distributed similarly; however, the outcomes regarding the level of ACC and PA usage differ significantly. The total number of PA and ACC activations in different DC types is shown in Fig. 3:

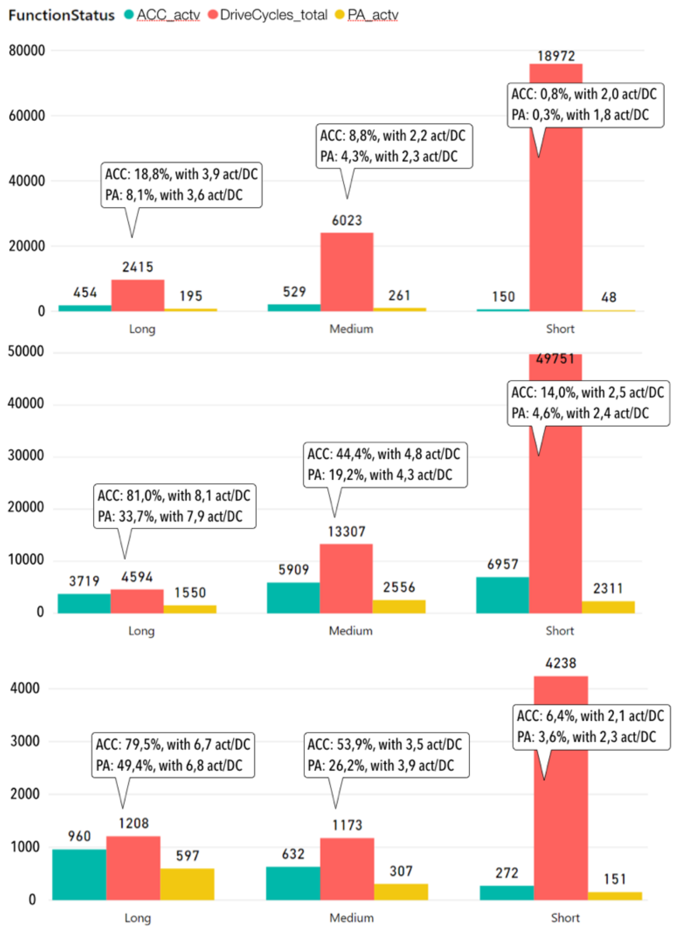

Fig. 3. Usage of ACC and PA functions on long/medium/short DCs together with the average number of activations per DC calculated in the three evaluated markets: (a) CN market; (b) SE market; (c) US market.

Comparing the data shown in Fig. 3, one can see that in the US market the usage of PA is higher compared to the SE and CN markets, with a higher use average and an average number of activations per single DC. The average use of PA in the US and SE markets is similar for long and medium DCs. However, in short DCs, drivers from the SE market use PA more.

Another observation is that in the SE market the ACC support has greater value for drivers than in the US market, where PA is used more than ACC.

The CN market has a similar trend on functions usage between long, medium and short DCs, but the average use is significantly lower than in other markets.

The differences in usage of ACC and PA functions across markets can be explained by differences in driving context parameters across markets. For example, the activation of the function shows the intention of a driver to use the function. However, the frequent amount of activations within a single DC can indicate poor driving conditions that force a driver to disengage from the system and then activate it again.

Moreover, the usage of ADAS in short DCs indicates a better function adoption. During short DCs drivers usually need less support from the automation for the following reasons: the duration is short, it is often conducted in a living area where the roads are smaller, and the allowed speed is lower. Moreover, the city road structure usually differs a lot from the roads outside the city (roundabouts, intersections, traffic lights, etc.). Nevertheless, drivers in the SE market showed better use of both functions in short DCs.

Finding 3: *Drivers in the SE market use ACC more effectively in limited driving conditions.*

To investigate more in-depth the use of ADAS functions in driving situations with limited conditions, we included the speed parameter, showing the use of functions in low speed (0-30 km/h). Fig. 4 shows that the drivers in the SE market indeed use ACC more effectively in short DCs and low speed.

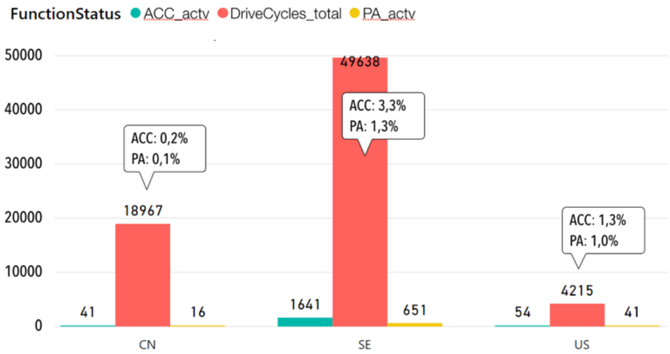

Fig. 4. The outcome of ACC and PA use levels in limited driving conditions in the CN, SE and US markets.

ADAS functions evaluated in this study were designed to be used in various traffic situations, including situations with dense traffic on the road. The use of the functions at low speed indicates the use of ADAS in a traffic jam if the speed limit for this road is higher. The data in Fig. 4 shows that drivers in all markets are still reluctant to use PA in dense traffic. Yet, drivers from the SE market start to recognize the benefits of the ACC in limited driving conditions slowly.

Finding 4: *Driver performance in the CN market varies from drivers who perform much higher than average in the market to drivers who do not use functions at all. This indicates a different driver perception of ADAS within one market.*

Investigating the low driver performance in the CN market specifically, an interesting data-based observation can be made: the data shows the existence of various levels of performance among different drivers. 23% of total drivers in the market show a relatively high level of performance for this market, and 26% of total drivers in the market do not use the functions at all, apart from one or two occasions when they did try the system. Fig. 5 graphically represents two groups of drivers, drivers with a high performance of both ACC and PA in this market (see Fig. 5a) and drivers who do not use ACC and PA (see Fig. 5b).

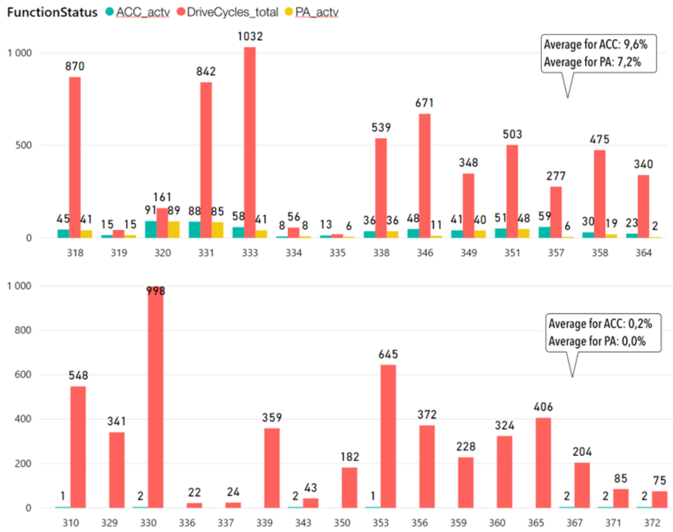

Fig. 5. Two groups of drivers with different level of ACC and PA usage in the CN market: (a) group of drivers with a high performance of both ACC and PA in this market; (b) group of drivers who do not use ACC and PA.

These results show that in general there are possibilities to increase the level of ADAS usage in the CN market. If a group of drivers could use the system to the average extent, equivalent to 9.6% for ACC and 7.2% for PA, respectively, then the road and traffic conditions allow them to do this. However, another group of users does not recognize any need for driver assistance, even though they paid to have this system in the vehicle. This fact signifies the involvement of driver-related factors that make drivers stick to a specific use strategy.

The situation with a wide range of driver performance is similar in all three investigated markets, which indicates that besides the driving context, driver perception plays a critical role in the way drivers understand and use ADAS. Differences in driver perception within the same market indicate different user awareness about the system, the attitude toward technology in general, as well as the trust and perceived usefulness of the ADAS functions. However, comparing driver behavior across markets, cultural differences should also be considered.

4. Discussion

The results of this study underline the importance of complex assessment of interactions between the driver, the system and the driving context, which correlates with the results achieved in our previous study [3]. This study reveals strong interrelation between the driver, ADAS and the driving context. Thus, the human-related aspects and the differences related to the driving context need to be considered while promoting ADAS in different markets.

One of the outcomes of this study revealed that to achieve a good understanding of ADAS capabilities and limitations is not an equally easy task for all drivers. On the one hand, it is not always easy to learn the system correctly. The design of driver assistance interaction does not include communication support between the driver and system aimed at explaining the system performance to the driver. The driver is often not able to notice the transition of ADAS functions from active to inactive. By this lack of driver support, ADAS developers want to make drivers focus on performing tasks and not to count on the system notifications alone. However, the lack of system support available to the driver often results in a poor understanding of how the system performs and what limitations it has. Another aspect is that different drivers' backgrounds, relation to the technology and previous experience with automated solutions affect the outcome the driver can achieve through the learning process.

As a reflection of market differences, various methods to capture these differences and adapt ADAS design to different markets are recommended. Semrau et al. [13] propose the use of the simulator to implement, calibrate and validate different traffic models. The study of Wang et al. [14] shows that bringing traffic scenarios into the ADAS design can help developers to achieve a better understanding of driver behavior.

The authors agree with the conclusion provided by Chen et al. [6], who underlined the need to develop a proactive educational system that would promote the driver's learning and understanding of ADAS. The diversity of chosen use scenarios in every market and across markets that we show in this paper indicates the need for different levels of support for ADAS users. To make this support feasible, multi-level data-driven communication for ADAS users can be designed. This would help drivers to learn and understand ADAS better and re-evaluate their own performance.

As part of communication support, the driver can be provided with various levels of system support. For example, the support focused on the stimulation of ADAS usage can help the driver to identify the correct context for ADAS functions usage better. The choice of explanation strategy can explain systems limitations, informing the driver why the function was eventually deactivated. Such system notifications can help in developing trust in the system performance, since the driver will learn that the system is reliable, and every deactivation always has a reason behind it. A warning strategy can be chosen to increase driver attention in situations where system performance is unstable or situations when the driver tries to use systems in the wrong way. Communication of this type can help ADAS users to easily learn, understand and safely use ADAS functions. This will improve driver confidence while using ADAS and consequently increase ADAS use level.

Conclusion

This study demonstrates the ability of vehicle data to evaluate driver behavior of ADAS functions across different markets in the real-driving environment. ND data collected and analyzed during the ND study helped to identify the differences in driver behavior and the driving context in the CN, SE and US markets and to identify the key differences in driving context and driver behavior across various markets that need further subjective investigation.

This paper also discusses possibilities to use vehicle data in the data-driven design of ADAS, where special consideration needs to be given to the infrastructural and cultural differences in various markets. An automated method of driving context identification in real-time situations can help to provide the driver with communication support, aiming to help drivers to learn and understand ADAS better and improve their own performance.

Acknowledgements

The authors would like to express gratitude towards Sweden's Innovation Agency VINNOVA for the funding of the project, Grant no 2018-05017. We also want to thank all the participants, without whom the study would not have been possible. Moreover, we are particularly grateful to Volvo Cars company for always being supportive and sharing their knowledge with us.

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