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Real-time Personalized Driver Support System for Pilot Assist Promotion in Different Traffic Conditions

Julia Orlovska[a,]*, Casper Wickman[a,b], Rikard Söderberg[a]

[a]*Chalmers University of Technology, Department of Industrial and Materials Science, SE-41296 Göteborg, Sweden*
[b]*Volvo Cars, 91200 Customer Experience Centre, Torslanda PV3A, SE-405 31 Göteborg, Sweden*

* Corresponding author. Tel.: +460731428333. *E-mail address:* orlovska@chalmers.se

Abstract

The complexity of advanced in-vehicle systems and level of automation provided is currently increasing, making the understanding of smart systems design and limitations challenging to a driver. As a result, misinterpretation of the system's capabilities can be detrimental to perceived usefulness and the system's usage. The personalized real-time driver support concept presented in this paper is designed to improve the driver's understanding of Pilot Assist (PA) and increase PA usage effectiveness in various traffic contexts. The designed communication informs drivers about PA capabilities in various traffic conditions, helping drivers recognize the appropriate context for PA activation and reflect on their own PA use strategy.

Keywords: vehicle data; ADAS; personalized support; context-awareness; context reasoning; real-time data processing

1. Introduction

Today, one of the current trends in the automotive industry is focused on developing automated in-vehicle systems to reduce the driver workload by assisting the driver in various driving situations. Volvo Pilot Assist (PA) is a good example of such systems. With the help of vehicle cameras and a radar system, PA provides longitudinal and lateral control of the vehicle, helping the driver automatically adjust the vehicle speed with regard to preselected rate and the time interval to a moving object in front, as well as implementing the ability to keep the vehicle in the road lane [1].

While there are undoubtedly great benefits associated with PA functionality, there are also some concerns related to PA use level and poor understanding of the PA abilities and limitations. The PA back-end architecture of function performance realization, which is based on vehicle data processing from multiple sources, is not always apparent to the user [2]. A lot of effort is required from a driver to understand what the automated system does, decide how he/she trusts the system, and how the system can be used. The misinterpretation of such system capabilities creates misunderstandings between the driver and the system and impacts the driver´s trust and reliance on the technology [3, 4].

On the other hand, there is great diversity among drivers, caused by different driving experiences, preferences, cultural differences, and attitudes toward technology and automation [5, 6]. Furthermore, the dynamic driving context, which is a combination of traffic, road and weather conditions, affects the performance of drivers [7], adding another dimension to the complexity of PA affective factors requiring full consideration [8] and [9]. As a result, the driver faces multiple factors that need to be assessed all the time. However, study results [6] showed that most of the drivers sampled did not significantly change their PA usage level for seven months. This indicates that the drivers usually predefine the level they want to be engaged with PA and stick to the chosen use strategy. Their initial understanding of PA capabilities and limitations delimits how they subsequently use the function.

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For the automotive OEM, it is challenging to develop the driver's trust in the system without explaining the complex processes of system performance since, for a driver, the use of PA is also combined with perceived safety. To help a driver become familiar with all contextual factors and the conditions where PA can support, reading the manual is often not enough. Moreover, the provided information always underlines that the driver has full responsibility for the driving activity on the current level of automation. Test-drives with professional supervision is another solution provided by OEMs that could help a driver become familiarized with the system. However, the number of in-vehicle systems and the amount of information received during the short period of the test-drive time hinders proper driver adaptation to the new environment. Therefore, personalized driver support, which helps drivers take their initial steps, is required [7]. It allows drivers to grasp the system performance and learn how and under what preconditions the system works effectively.

Several studies for personalized driver support have been presented [10-12]. These report the positive effects of such support on the user. This work indicates that to design personalized assistance, two specific conditions need to be considered. First, driver support needs to be specifically designed for the system, since in-vehicle systems differ in their needs, provide different functionalities, and consider different contexts for system performance realization. Second, the automotive context requires real-time context-aware support that is able to capture the context and react to its changes [13].

In this article, we propose a design of real-time personalized support for PA users. The design is based on the data-driven communication framework, presented in [14] and provides context-aware evaluation of the dynamically changed traffic situation in real-time, as well as focusing on promoting PA usage in varied traffic situations. The main goal of the real-time personalized support presented in this paper is to explain to drivers what abilities and limitations PA has and explain how PA can be used more effectively in different traffic conditions by helping to identify suitable traffic conditions for PA activation. As an outcome of this support, we expect drivers to increase their understanding of the PA function, develop confidence in the PA context identification, and eventually increase PA use.

2. The design of personalized support for PA users.

Personalized driver support in real-time is designed to improve the effectiveness of PA usage. It aims to make drivers reflect over their own PA use strategy by informing them about the additional context where PA can be effectively used, helping them to identify this context in real-time situations. Several sequential steps need to be designed to ensure this type of support, where different purposes are served, and various types of data are used. The main steps for ensuring personalized support of PA users are presented in Fig. 1.

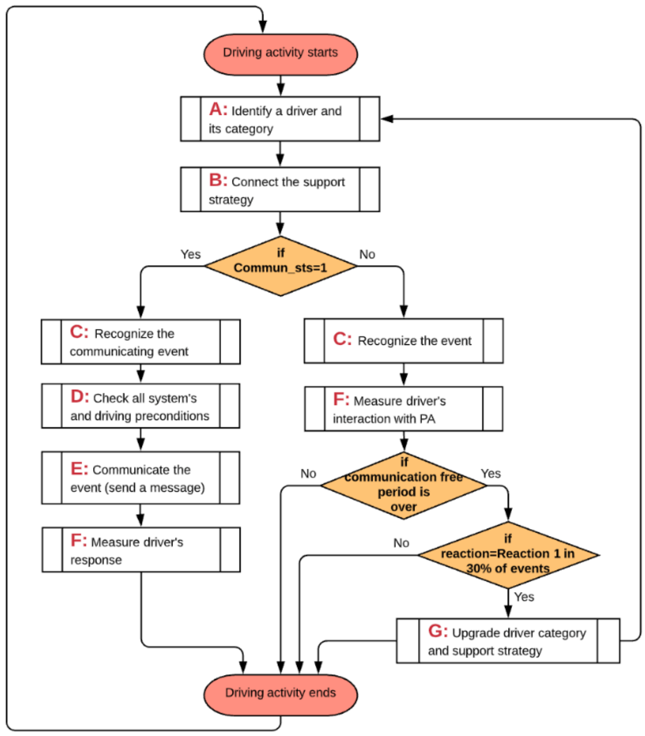

Fig 1. The sequence of steps for personalized support of PA users in real-time

According to the design of personalized driver support, the driver is not provided with additional assistance in all driving activities. The personalized support for PA users consists of two phases: the phase when the driver receives the system's notifications and the phase with the support-free time when the driver is not guided but uses PA as he/she wants. During support-free time, the effect of previously provided communication is measured, and the need to update the driver category and connected category support strategy is evaluated. The design of the personalized support steps is described in more detail below.

2.1. Step A: identify a driver category

To provide a user with personalized support, we need to recognize who our driver is and how he/she uses PA. Recently, different methods for driver identification, based on a combination of different user data types, were proposed [15, 16]. Some of these methods can be tested and implemented in this framework as additional modules for driver identification. This particular study does not propose a solution for driver identification. Instead, it provides a support strategy only for drivers who have their vehicles in private use and do not regularly share them with other people, meaning that the vehicle ID is the same as the driver ID.

As for the classification of a driver in a specific category, our previous research [7] revealed a possibility to measure driver performance and the level that different functions are used. Analysis of performance data helped identify groups of drivers who need additional support to increase their interactions with the PA. Based on vehicle data collected in our previous research, the drivers' categorization with regard to PA use in various traffic conditions was performed. The driver categories shown in Table 1 were identified.

Table 1. Driver categorization based on PA usage in various traffic conditions

Category	Description	Sparse traffic	Dense traffic
Dr.Cat.1	Drivers who do not use PA at all	0-5 activations	0-5 activations
Dr.Cat.2	Drivers who use PA only in sparse traffic conditions and to a low extent	< average level	0-5 activations
Dr.Cat.3	Drivers who use PA in both sparse and dense traffic conditions to a low extent	< average	< average
Dr.Cat.4	Drivers who use PA only in dense traffic to a low extent	0-5 activations	< average
Dr.Cat.5	Drivers who use PA only in sparse traffic conditions to a high extent	≥ average level	0-5 activations
Dr.Cat.6	Drivers who use PA in sparse traffic to a high extent and in dense traffic to a low extent	≥ average level	< average
Dr.Cat.7	Drivers who use PA in dense traffic to a high extent and in sparse traffic to a low extent	< average	≥ average level
Dr.Cat.8	Drivers who use PA in both sparse and dense traffic conditions to a high extent	≥ average level	≥ average level
Dr.Cat.9	Drivers who use PA mainly in dense traffic to a high extent	0-5 activations	≥ average level

The primary focus of our study is drivers from categories 1-6. Their performance indicates that they do not use PA, use it only a little, or use it in sparse traffic when the road traffic situation is more relaxed. Drivers from these driver categories have the potential to improve their performance to shift into categories 7-9, which indicate the satisfactory levels of PA usage in this study.

2.2. Step B: connect the support strategy

Based on the driver category identified in the previous step, we connect a support strategy to the driver to improve his/her performance if needed. Three main support strategies have been designed: (1) promotion of PA in sparse traffic; (2) promotion of PA in dense traffic; and (3) promotion of PA in both sparse and dense traffic. Depending on the driver's category, an appropriate support strategy is chosen and regularly reevaluated.

Support strategy 1 is chosen to promote usage in sparse traffic. This strategy is assigned only to drivers from driver category 1. For these drivers, the promotion of PA in sparse traffic would help to start their interactions with PA in less stressful traffic conditions, which hopefully will lead to a positive driver experience and a change in their attitude towards the PA functionality.

Support strategy 2 is designed for drivers who need support help in both sparse and dense traffic conditions, since their activity level in both traffic conditions is significantly lower than average. Support strategy 2 is assigned to driver categories 2-4.

Support strategy 3 aims to increase PA usage in dense traffic and applies to driver categories 5 and 6. Drivers in these categories use PA in sparse traffic but are reluctant to try it in higher-density traffic situations. In this case, additional support will help a driver identify dense traffic suitable for PA usage and encourage the driver to try PA in more advanced traffic conditions.

Drivers identified as drivers from categories 7-9 do not receive additional support, since their performance is already considered acceptable. If drivers show a significant PA usage level in dense traffic, the proposed design does not try to improve their performance further. Our goal is to illustrate the abilities of PA in different traffic conditions, to help drivers to learn how to recognize suitable conditions for PA activation in real-time, and possibly to make drivers reflect over their own PA use strategy.

As an output of step B, the support strategy gets assigned to a particular driver. Thus, in step C, we know what type of traffic conditions we need to identify in real-time to provide support to each driver.

2.3. Step C: recognize the communicating event

The following data signals were used to distinguish sparse and dense traffic conditions: S(l) - speed limit, S(d) - driving speed, R(d) - reaction distance to the vehicle in front, and t - time that all three conditions last. Table 2 shows how sparse and dense traffic is identified using this data:

Table 2. Driver reactions to the communicated event

Data parameters	Sparse traffic	Dense traffic
Speed limit, km/h	$S(l) \geq 30$ km/h	$S(l) \geq 30$ km/h
Driving speed, km/h	$S(d) \geq S(l)-20$ km/h $S(d) \leq S(l)+10$ km/h	$S(d) \leq S(l)-20$ km/h
Reaction distance, sec	$R(d) \geq 3$ sec	$R(d) \leq 1$ sec
Time, sec	$t \geq 30$ sec.	$t \geq 60$ sec.

Two further conditions, when the use of PA will not be promoted, were identified. These situations are connected to the safety aspects and the current limitations of PA functionality. The first situation is when the speed limit is equal to or less than 30 km/h. Such a reduced speed limit is usually set as an indication of a residential area where pedestrians and playing children can appear, or there may be different problems with the road condition. Since, due to its limitations, PA might not recognize a person or small obstacles on the road, the use of PA in such circumstances is connected to the safety aspect and is not recommended by the OEM. Another condition when the communication will not be provided is when a driver is exceeding the speed limit by more than 20 km/h. In this case, to distract a driver with any notifications could be contradictory to safety aspects and could result in a situation where the notification distracts the driver's attention from the road when it is most needed. Moreover, there is a risk that PA is not able to handle the situation on the road if it is activated at a speed that is much higher than allowed.

The output of step C is the identification of traffic conditions when the specific driver needs personalized support.

2.4. Step D: check all system and driving preconditions

Step D, where all prerequisites are checked, needs to be implemented before provided support. For PA specifically, the driving context, which includes traffic, road, and weather conditions, is crucial, since many PA performance limitations are connected to it [7]. For example, PA requires clear markings of the lane to function. Furthermore, PA is not recommended for use when there is a great deal of water, slush on the road, or heavy precipitation, since this negatively affects visibility on the road or results in slippery road conditions [1]. Since the traffic conditions were checked during the previous step, the road and weather conditions need to be evaluated in this step. We need to check if the lane is represented and what type of road it is. The road type is determined by the speed limit that indicates how a driver is allowed to drive on the road. For example, a speed limit of 120 km/h represents a high way, a speed limit of 30 km/h most likely represents a residential area, etc. The presence of lane marks is assessed by the output signal of a Lane Keeping Aid (LKA) function that we readout and control in this step. With regard to weather conditions, we control the precipitation by reading out the wiper's activation status and its levels. If the wiper's status is equivalent to or higher than 4 (from the range 0-6), we conclude that the level of precipitation is high, and the promotion of the PA in such conditions is not provided. The fog illumination status indicates the visibility on the road. If fog illumination status is On, the visibility is limited, and PA promotion is postponed. Another parameter is ambient temperature. It helps to identify slippery road conditions. If the ambient temperature is +/-2ºC, there is a high possibility of icy road conditions, and PA cannot be promoted.

In parallel to the driving context, driver intention, such as preparing for a maneuver, needs to be assessed. If a driver plans to change lane, overtake a car, or turn to the right or left, it means that he/she will change or cross the road lane. In this case, PA will not continue functioning and will switch its status to standby mode. This means that it would be useless or even confusing for a driver if we advise PA activation in these conditions. The proposed design therefore presumes that if the turning indication is On, communication with the driver will be postponed.

Further, PA uses vehicle cameras and radar to maintain a set speed or automatically adjust the vehicle's speed concerning other objects moving in front. If radar or cameras are not functioning or cannot deliver the data due to mud or other reasons, the PA cannot perform. Thus, it is incorrect to promote PA without checking associated equipment. If following our recommendation, the driver will not get PA activation as promised, he/she would judge PA performance as unreliable.

As an output of step D, we obtain confirmation that all parameters are satisfied for all set criteria at the moment before communication.

2.5. Step E: communicate the event

The communication is designed so that, together with the driving event (which is different for different driver categories), the drivers' experience regarding the use of these functions is considered. If the driver belongs to Category 1, the driver might not have used or even tried PA before. Thus, together with the recommendation, the driver will receive an explanation of how to navigate PA on the menu. Drivers from categories other than 1 will receive only a notification of the traffic context, since the historical data shows that these drivers have used PA before and, therefore, know how to operate it.

Further, depending on the driver's reaction, additional support can be designed. For safety reasons, it is extremely important that drivers understand PA status indications and know whether PA supports them or not. Therefore, if inexperienced drivers follow our recommendations, they will receive an additional notification explaining the way drivers should control PA status indications.

2.6. Step F: measure the driver's response

When the message is sent, the driver's reaction to this communication is of importance. The driver's reaction to the notification informs us of how the communicating strategy can be adjusted to fit current driver needs. In this case, we have extracted three different driver reactions, which are presented in Table 3.

Table 3. Driver reactions to the communicated event.

Driver reactions	Description
Driver reaction 1	PA is activated under the conditions we proposed
Driver reaction 2	PA is activated but under other conditions
Driver reaction 3	PA is not activated

When the driver's reaction to the provided support is understood, this can be used for assessment and possible adjustment of the support strategy in step G.

2.7. Step G: adjust the communicating strategy

The driver category and associated support strategy can be upgraded if the driver demonstrates usage of PA under the proposed conditions during the communication-free periods when the driver's reaction is not affected by our notifications. Thus, the off time is required to re-evaluate driver performance. The length of the off time between two communication sessions is decided based on the summary of the driver's reactions to the provided communication. If a driver's response is positive (driver reaction 1) in more than 30% of cases, the driver is given two days off from the personalized support. If this is not the case, only one day off is given until a positive response is obtained more often. During support-free periods, the system will control if a driver can recall a previously given recommendation and activates PA in the recommended traffic conditions.

Before the next communication session, the summary of driver reactions for all PA activations made is evaluated. If driver performance reaches the set threshold of 30% per 100 detected cases, the driver category is updated. If this does not happen, another round is scheduled. Depending on the driver's starting category, a series of upgrades might be required before the communicating support will reach one of categories 7-9 and will be discontinued. The schematic for upgrading the driver category and support strategy is presented in Fig. 2.

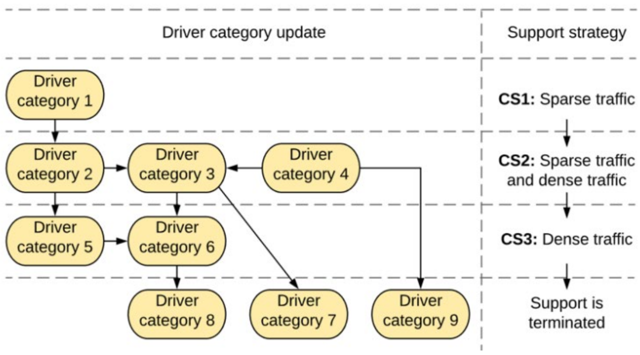

Fig. 2. Schematic for upgrading of driver category and associated support strategy.

The output of step G is the calculated time until the next communication session, the decision regarding the driver category update that needs to be delivered to step A, where the driver category will be regulated.

3. General application of the framework to the design of real-time personalized support.

The authors believe that framework steps A-G could be used for any personalized support after a certain generalization. The parameters for Driver Categorization need to be chosen based on the new objectives. For example, if we want to promote another system, this system use and its context should be in the baseline for Driver Categorization in step A. The support strategy, designed in step B, should be connected to the study's purposes, which could be different from promoting a function, as presented in this paper. Other communication strategies could be, for example, a warning strategy to prevent unintended use of the function or an explanation strategy to communicate function status or reason for the function's deactivation/not activation. The support strategy needs to be designed based on the specific study's purposes.

Based on the same logic, the data points for a communication event recognition used in step C, and car performance monitoring used in step D, have to be chosen considering the system, its performing context, and the performance of systems related to the one under investigation.

For step E, there are plenty of ways to provide support to the driver: message on the screen, graphics, voice, alarm signal, and others, including even fully automated support when the vehicle automatically adjusts system behavior without informing the driver. The combination of the communicating techniques should be done with the respect to the safety regulations. Driver distraction should be minimal, so that the driver should be able to focus on the primary driving tasks. Another thing that needs to be considered is the priorities of the in-vehicle events and notifications. If another in-vehicle notification occurred at the same time as a notification from the supported function, the notifications must be communicated to the driver based on their priorities. This becomes especially important for the fully integrated app.

Finally, steps F and G, combined into the self-learning module, could also be designed differently. In this work, performance-based logic is used. However, this approach can be exchanged for ML algorithm(s) that learn from the driver responses, monitor the change of driver' use strategies, and decide how soon this driver reaches the next level, or decides what communication strategy is best at that moment.

4. Discussion

In this section, we discuss the main limitations and propose possible improvements to the design of PA users' additional personalized support.

The automotive sector has specific nuances that distinguish in-vehicle systems from systems installed on any stationary or mobile device. Driving and being inside a vehicle, a driver creates two types of contexts: the driving context, which relates to the driving conditions in the road, and the in-vehicle context, which refers to the driver activities inside the vehicle. This dual context increases the number of parameters that need to be considered while the driver support is designed. The in-vehicle context, such as using a phone, the distraction caused by passengers, the interaction with HMI, etc. can also be relevant at the moment of communication, since this indicates the driver's state and driver workload. If the moment of sending the notification is chosen without the assessment of the in-vehicle context, the notification can be missed or even distract the driver from other tasks he/she performs. This particular design so far considers only the outside context associated with the driving activity on the road. The in-vehicle context was not assessed, due to reduced vehicle data availability able to support the in-vehicle context monitoring.

Another design limitation is that the current design does not support a driver's input. However, a driver's support strategy needs to be decided depending on both driver performance data and a driver's desire to receive this support. Depending on the driver's preferences at the current moment, the driver should be able to activate or deactivate support, as well as adjust the frequency of interactions manually. Such a module will be further developed and introduced after we test the design of personalized support in the pilot vehicle with professional users. Real users will be able to decide if they want personalized support or not and to what extent.

One more area for further investigation is the way the notification is represented to a driver. One of the key factors of personalized support success is the "intelligence" of communication. If the vehicle constantly sends the same notification in the same context, the driver will soon understand the primitiveness and simplicity of the communication strategy and lose interest in it. Thus a special consideration could be paid to the design of notifications and how these announcements are represented (e.g., graphic, text, voice, or combined messaging). According to our current setup, the support information will output on an additional screen interface mounted in the vehicle. This setup is suitable for a pilot study. However, in the future, if personalized driver support runs as one of the vehicle applications with the output on the screen of the instrument panel, the credibility of such support will significantly increase.

Despite some possible improvements, the personalized driver support designed in this paper fulfills its needs, since it allows provision of information about traffic conditions in real-time and helps drivers learn more effective use of PA. The practical implementation of the design is the next step. A pilot study will be conducted, where the authors plan to evaluate how much drivers appreciate this support and whether it affects drivers' predefined scenarios for the usage of PA.

Conclusions

In this article, we proposed the design of a personalized driver support system for PA promotion in different traffic conditions. The design supports the context-aware evaluation of the dynamically changed traffic situation in real-time. It informs drivers about PA capabilities in various traffic conditions, helping drivers recognize the appropriate PA activations context and reflect on their own PA use strategy.

During the practical implementation of this design, which is planned as a next step, the main focus will be on validating set rules for identification of traffic situations and threshold values corresponding to these rules.

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