Cognitive Vehicle Design Guided by Human Factors and Supported by Bayesian Artificial Intelligence

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Abstract. Researchers and automotive industry experts are in favour of accelerating the development of "cognitive vehicle" features, which will integrate intelligent technology and human factors for providing non-distracting interface for safety, efficiency and environmental sustainability in driving. In addition, infotainment capability is a desirable feature of the vehicle of the future, provided that it does not add to driver distraction. Further, these features are expected to be a stepping-stone to fully autonomous driving. This paper describes advances in driver-vehicle interface and presents highlights of research in design. Specifically, the design features of the cognitive vehicle are presented and measures needed to address major issues are noted. The application of Bayesian Artificial Intelligence is described in the design of driving assistance system, and design considerations are advanced in order to overcome issues in in-vehicle telematics systems. Finally, conclusions are advanced based on coverage of research material in the paper.

Keywords: Autonomous vehicle · Human-factors · Cognitive vehicle · Advanced driving assistance system · Automation in driving

1 Design Features of the Cognitive Vehicle

Since the emergence of the *intelligent vehicle and highway system* (IVHS) field a few decades ago, intelligent vehicles have taken several giant leaps and the car of the future is expected to be "smarter" and "autonomous" with safeguards regarding shared authority with human driver. Researchers and automotive industry experts are leaning towards a vehicle design that exhibits "cognitive" features. This can become a reality only if intelligent technology and human factors are integrated for providing non-distracting interface for safety, efficiency and environmental sustainability in driving. In addition, infotainment capability is a desirable feature of the vehicle of the future, if it does not add to driver distraction.

Early R&D in the cognitive car was described by Heide and Henning [1], Stiller et al. [2], and Hoch et al. [3]. The National Research Council of Canada (NRC) took an interest in the subject by developing a Cognitive Vehicle Technology Platform that was intended to avail opportunities in the rapidly growing field of automotive information and communication technologies (ICT). The NRC's R&D in this area was a response to

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both proliferation of on-board sensors and electronic controls for enhancing safety and performance, and a rising demand for integrated and wirelessly connected communications and infotainment devices [4].

Cognitive connected and autonomous vehicle research aims at integrating intelligent technology and human factors. Although R&D efforts underway in many countries are timely, there is a need to go a step beyond the existing programs in a number of key high priority areas. Figure 1 presents R&D themes, classified according to function. These themes cover capabilities with recognized market value and are fully integrated. For various themes, the components are application-specific (e.g. open architecture for multi-functional advanced driving assistance system design).

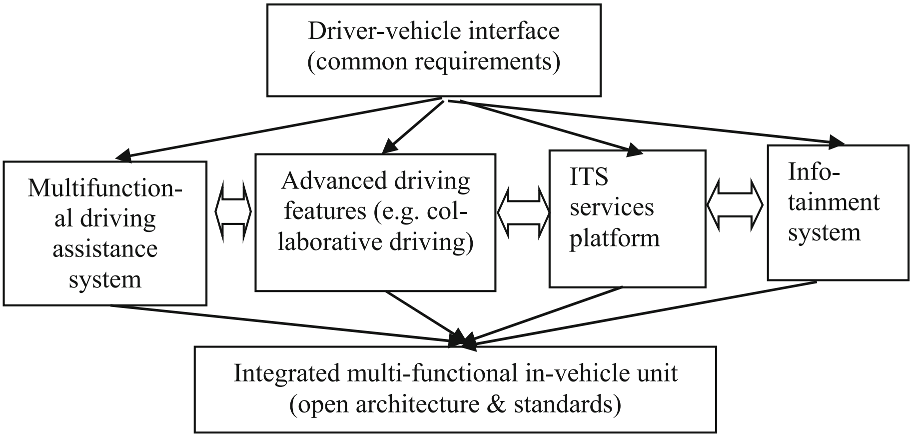

Fig. 1. Cognitive vehicle R&D themes

A key area of research is the driver-vehicle interface that comes into play in all functions of the vehicle of the future. In this case, common requirements are to be defined in support of the following components:

- Driving assistance system
- Advanced driving features such as collaborative driving
- Intelligent transportation system (ITS) services platform
- Infotainment system

In addition to the above functional components of the advanced technology vehicle, an in-vehicle unit is required with the capability to integrate multi-functions noted above. As in the case of the design of the individual components, this in-vehicle unit should exhibit open architecture and standards.

The rationale for developing cognitive vehicle features is provided below.

- The full potential of smarter transportation valued by drivers, especially younger generations of drivers, cannot be achieved without the cognitive vehicle.
- In the era of policy trends encouraging the convergence of transportation systems and services, the cognitive vehicle is central to future intelligent transportation.
- Sensors and communication devices account for substantial investments in transportation systems. Without the cognitive vehicle, the instrumentation of transportation will not be effective.

Based on industry analyses and research studies, cognitive vehicle features of high market potential are defined this paper. As a step in this direction, the following observations on improving vehicle design are noteworthy.

- For improving safety, mistakes made by distracted drivers should be reduced.
- Selected active safety features are likely to gain favour with the users, provided that their designs are improved substantially [5].
- Advanced driver assistance (driver support) systems that take into account “driver intent” are necessary.
- Ability to support non-distracted and non-aggressive driving in longitudinal and transverse guidance of the vehicle – if activated by the driver for reasons of comfort, convenience and safety in driving, will be a highly valuable design contribution.
- Natural non-distracting driver-vehicle interface that reduces driver stress and workload is essential.
- Ability to connect with other vehicles, infrastructure and devices is essential for future generation of vehicles [6].

2 Issues in Highly Automated Driving and Design Solutions

There are major issues in driving that a cognitive vehicle design should address. These are driver distraction, driver workload, driver stress, and inconsistent and confusing design features. In addition to common general distractions (e.g. passengers, food), there are concerns that in-vehicle technologies and applications may add to common sources of distractions. In-vehicle access to intelligent transportation system services and infotainment may add to distraction unless their designs are non-distracting. Even a driving assistance system and cooperative driving technologies may have a distracting side effect in the form of too many warnings and false alarms.

Although technologies play an important role in developing a cognitive vehicle, there is a need to go beyond strictly technical features by including well-researched means for vehicle-human interaction. Table 1 defines features that should be built into the design of the cognitive vehicle in order to enable challenging applications.

Table 1. Cognitive vehicle features and applications

Features	Applications
Ability to provide non-distracting user interface	For all driving, ITS service, and infotainment tasks, a non-distracting interface will be required
Awareness of position and surroundings	Cooperative collision avoidance, collaborative driving, ITS services (e.g. navigation)
Ability to gather and send out data	Safety, traffic control and management, ITS services
Ability to process data	Implementation of algorithms for safety, efficiency, and eco-driving
Ability to cooperate/collaborate	Cooperative collision avoidance, collaborative driving
Communication for active safety	Informing driver and neighbouring vehicles about potential collision hazards (e.g., informing left-turning vehicles about pedestrian on a crosswalk)
In the event of a crash, capability to send and receive information	Emergency/safety applications
Informs the driver about situations (warnings, advice); defines how to deal with driver distraction and aggressiveness	Safety applications (e.g., informing driver about object or stalled vehicle and aiding the driver in making an early lane change, collision warning)
Diagnostic capability	Enhancement of efficiency in the use of vehicle and convenience of the driver
Infotainment capability (while managing driver distraction)	Driver and passenger convenience

Taking each component of the cognitive vehicle design, illustrated in Fig. 1, the following figures highlight the problems as well as measures required to solve these through vehicle design. Figure 2 notes the requirements of driver-vehicle interface applicable to all components of vehicle design and ultimately operation in the real world.

In developing driver-vehicle interface designs for various applications implied by R&D themes illustrated in Fig. 1, details of the following common guidelines will be needed:

- Placing minimal demand on driver workload
- Reducing the frequency of driver multitasking
- Reducing the complexity of distracting tasks thus lowering demand on driver attention
- Reducing driver workload by managing available options
- Accounting for driver distraction with adaptive algorithms
- Monitoring driver attention status using in-vehicle technologies for alerting drivers.

Driver-vehicle interface (common requirements)

- Interaction processes between driver, vehicle, portable device, and driving environment
- Driver distraction and stress
- Driver workload issues
- Maintenance of consistency
- Driver acceptance (criteria of relevance, usability)

Fig. 2. Driver-vehicle interface

A major challenge in developing the cognitive connected vehicle is to add an advanced driving assistance system in order to meet the objectives of safety, convenience, economic efficiency, and environmental sustainability in driving. The automotive industry is very keen on innovating in this part of the cognitive vehicle design. See Fig. 3 for design features.

Multifunctional advanced driver assistance system design

- Open architecture & algorithms
- Non-distracting design
- Interface with portable device
- Sensor network for data capture
- Integrated sensing for state estimation
- Communication systems
- Mechatronics/MEMS for driver assistant

Fig. 3. Driver assistance system design

In order to put technology to work for supporting new and advanced driving features, research is underway in collaborative driving and other applications of vehicle-to-vehicle and vehicle-infrastructure communications. In addition to maximizing the throughput from highways, environmental benefits are achievable. In order to safeguard safety and enhance user acceptance, technology and human factors have to be integrated in designs (Fig. 4).

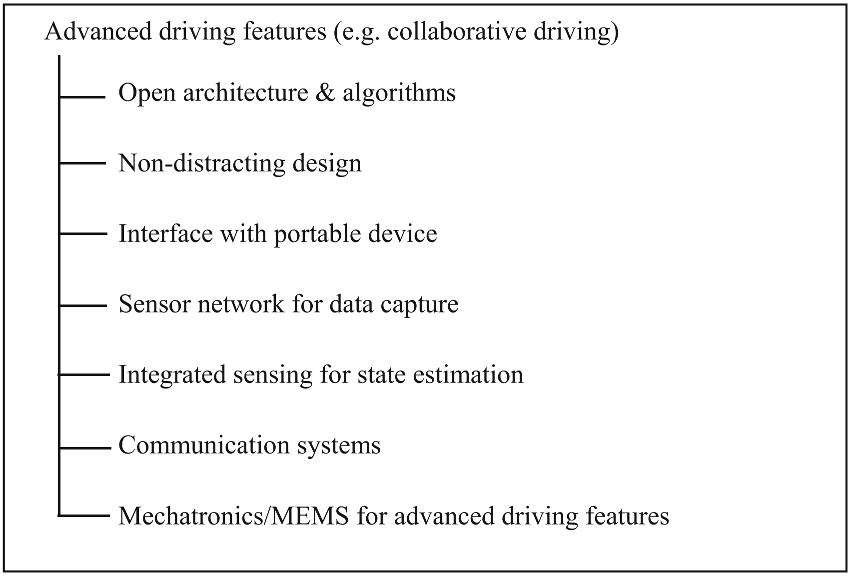

Fig. 4. Design for advanced driving features

For enhancing the value of a future vehicle to the owner, in addition to other features, it is necessary to formally incorporate the special requirements of intelligent transportation system (ITS) and services in vehicle design. The market potential for cognitive vehicles with integrated non-distracting and intelligent transportation features is very large. Examples of ITS services include parking information, route guidance and other traveller information, and insurance and road user charges that are expected to become on-line services (Fig. 5).

The infotainment system is intended to receive a wide variety of information and data of interest to the human driver and other occupants of the vehicle. In case of autonomous driving, such information can be used as well for non-driving functions. In addition to receiving information on-line, the internet capability will allow connectivity with out-of-vehicle sites. The buyers of advanced technology vehicles are likely to be

ITS services platform

- Open architecture & algorithms
- Non-distracting design
- Interface with portable device
- Sensor network for data capture
- Integrated sensing for state estimation
- Communication systems

Fig. 5. Design for ITS services

keen on this convenience feature, which could also have the added entertainment value. On the negative side, due to the potential for prolonged communications such as requesting downloads or viewing received information, driver distraction becomes an issue. Therefore, the design of the infotainment system requires much attention regarding human factors (Fig. 6).

Infotainment system design

- Open architecture & algorithms
- Non-distracting design
- Interface with portable device
- Communication systems

Fig. 6. Design for infotainment system

3 Application of Bayesian Artificial Intelligence

Korb and Nicholson have defined artificial intelligent (AI) as the "intelligence developed by humans, implemented as an artefact" [7]. The Bayesian methodology is best suited for system design and decision analysis when uncertain "states of nature" are encountered, but knowledge of uncertain factors such as driving states, driver distraction and driver intention can be refined with additional information acquisition.

Bayesian AI can be of much value in cognitive vehicle design, especially in the design of the advanced driving assistance system. For an introduction to the Bayesian AI application to driver assistance design, please refer to Khan [8, 9]. Applications in the design of driving assistance system can manage driver workload, warn drivers of risky situations, and monitor driver performance. Illustration of countermeasures directed to the driver shows the potential to overcome the distracted driving problem [10].

For design purposes, the Bayesian artificial intelligence integrates two cognitive features of the advanced driving assistance system. The first one models a desired human action (e.g., non-distracted non-aggressive driving). The second is to model the rational view of what is "optimal" and apply it as a decision criterion.

Khan has suggested a three-step approach. The use of algorithms for Bayesian analysis of driving missions is the first step. Next, is the computation of expected gains/utilities. Finally, the optimal course of action is identified on the basis of maximum gain/utility criterion [11].

Application of intelligent technology and human factors in the driving assistance system design will provide seamless transition between human control and automation. This advance in design should overcome driver dissatisfaction with false alarms, which arise due to lack of formal treatment of distracted driving and driver intent in existing driver assistant designs. The advanced design reported by Khan has the capability to avoid rear as well as lateral crashes. The high-level architecture of the advanced driver assistance system is shown in Fig. 7.

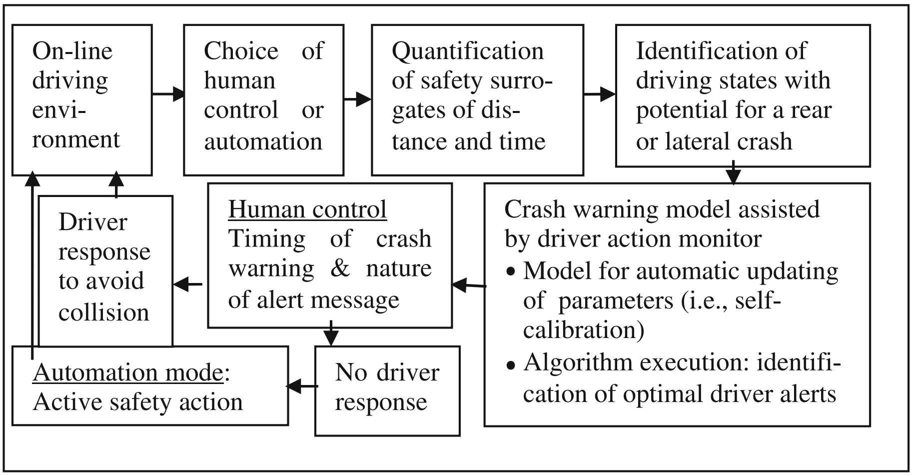

Fig. 7. High-level architecture of driving assistance system's safety function [11].

4 In-Vehicle Telematics Issues

In-vehicle telematics can distract human driver and encourage multi-tasking. To overcome such issues, the advanced driving assistance system provides a solution. To illustrate how driving can be affected by the use of in-vehicle telematics, driving simulator data is presented here.

Driving simulator experiments were carried out with the participation of young drivers who were given distracting tasks to do while driving. The simulator outputs contain useful information on the driving behaviour of participants. In non-distracted driving, the choice of speed, acceleration/deceleration rates, headway to the leading vehicle, and gap acceptance when changing lanes provide information on the lack of or presence of aggressiveness in driving.

During a driving mission, if the driver becomes distracted and is not alert enough to perceive a hazard, this results in insufficient distance for stopping or to make an evasive manoeuver. Excessive time could be required by a distracted driver to perceive the hazard and then excessive deceleration rate (close to 1 g) will be required to avoid a collision.

Such sudden emergency braking sends shock waves in the traffic stream and is known to be a safety hazard. Also, a distracted driver may experience lane migration and violate safety distance in the lateral direction.

Figures 8, 9, 10, and 11 illustrate the driving record of a young driver who was using a hands-free phone and encountered a hazard that required action. In this driving trajectory, rapid changes between deceleration and acceleration can be seen. In addition, the acceleration pattern is unusual. Although the perception-reaction time of 1.17 s was acceptable, other attributes of driving could be assisted with the cognitive vehicle's advanced driving assistance system.

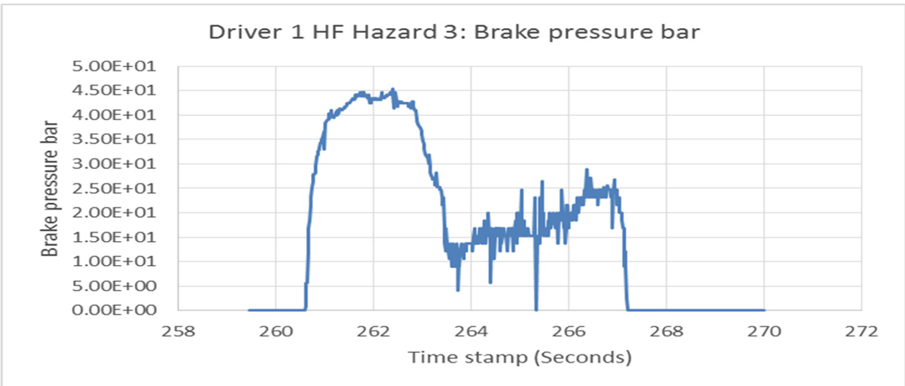

Fig. 8. Brake action while using hands-free communication device

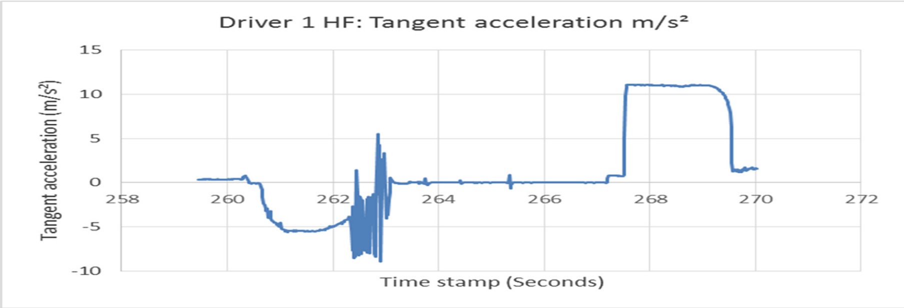

Fig. 9. High level deceleration and acceleration pattern

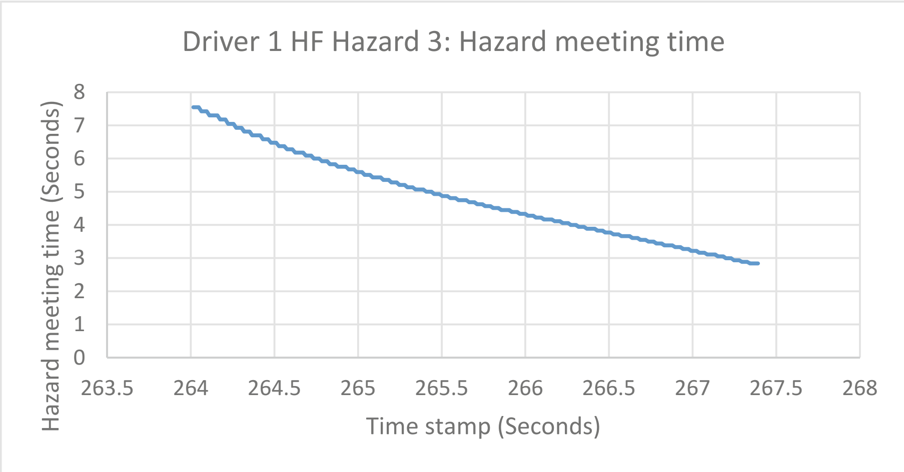

Fig. 10. Hazard meeting time

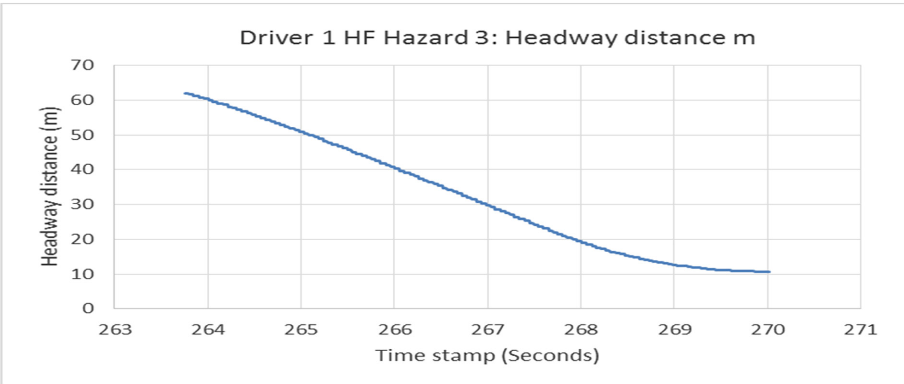

Fig. 11. Headway distance to leading vehicle

5 Conclusions

(1) The design of driver-vehicle interface should enable the provision of information in an effective manner and at the same time should eliminate or at least minimize distractions that contribute to elevated probability of crashes.
(2) Through new knowledge such as carefully designed application of Bayesian AI, in-vehicle systems will evolve that will be effective in serving their function, including necessary and optimized alerts.

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