The Hexagonal Spindle Model for Human Situation Awareness While Autonomous Driving

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Abstract. Over the years, many automobiles have been installed with automated functions (Debernard et al. [5]). Traditional automotive manufacturers in addition to newly emerging IT companies have been recently developing autonomous driving functions. Common sensor technologies have recently been discussed, although human situation awareness regarding autonomous driving systems has not. According to Endsley, the development of autonomous vehicles reveals three major problems [8] that may affect drivers' overall safety, as the autonomous driving system is not perfect; thus, if any problems occur that disable the driver and autonomous system from maintaining safe driving, a serious car crash becomes a possibility. Therefore, this paper suggests that the hexagonal spindle model be employed for human situation awareness during autonomous driving. Through the model, Human Machine Interface (HMI) designers may be expected to consider various aspects of human situation awareness during autonomous driving to help drivers implement driving strategies when facing unanticipated events on the road.

Keywords: Situation awareness · Cognitive engineering model

1 Introduction

1.1 Development of Autonomous Driving

In recent years, autonomous driving has been discussed as a significant topic and has obtained broad public attention (Brenner and Herrmann [1]). Over the years, many automobiles have been installed with automated functions (Debernard et al. [5]). Many traditional automotive manufacturers such as Ford, Toyota, and Hyundai as well as newly emerging IT companies such as Google, Apple, and Samsung have recently been developing autonomous driving functions. Common sensor technologies have recently been discussed, although, in regard to the cognitive engineering aspect, human situation awareness designed alongside autonomous driving systems has not yet been sufficiently discussed. This means most manufacturers are generally concentrating on improving the functions or quality of their automated systems but consequently neglecting manual functions of cars equipped with autonomous driving systems.

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1.2 Definition of Autonomous Driving

National Highway Traffic Administration (NHTSA) categorised automated driving into six levels [11].

- No-Automation (Level 0): There is no automation. The driver performs all driving tasks; brake, steering, throttle, and motive power.
- Driver Assistance (Level 1): Basically, the vehicle is controlled by the driver. However, some specific functions involved in the vehicle, that helps the control of the driver.
- Partial Automation (Level 2): The vehicle consists of some automated functions such as acceleration and steering wheel control, but the driver should be engaged with the driving tasks and monitoring the driving environment.
- Conditional Automation (Level 3): The driver should present in the vehicle, but the driver does not need to monitor the driving environment. The driver should be ready to take control of the vehicle all times with notice.
- High Automation (Level 4): The vehicle can control all functions under certain conditions. The driver may have option to control the vehicle.
- Full Automation (Level 5): The vehicle can control all functions under all conditions. The driver may have option to control the vehicle.

In this paper, we believe Levels 3 and 4 possess powerful situation awareness systems. In addition, although full automation (Level 5) does not require a human driver, humans drive the vehicles that possess conditional automation (Level 3) and high automation (Level 4) due to several reasons that will be discussed in the following section. Therefore, we discuss the cognitive engineering model to consider how the powerful situation awareness systems inform drivers when situational events that may influence the driving strategy unexpectedly occur.

1.3 Human Driving with Autonomous Driving Vehicle

Although the autonomous driving system has been developing dramatically, many cases can be expected wherein drivers continue operating autonomous driving vehicles manually. There are several examples of humans manually driving autonomous driving vehicles; for example, the driver may prefer driving by him/herself for fun, as many drivers prefer manually driving for fun. Cai's and Lin's research suggests that drivers potentially express various emotions while driving, such as calmness, pleasure, happiness, and fear [3]; in addition, they may enjoy speedy driving, controlling the vehicle, and even improving their driving skills. On the other hand, many people do not trust the autonomous driving system. Various types of driver support systems have been recently developing in the automotive domain to improve autonomous driving systems that may be proactively aware of the road's situational environment. Although autonomous driving systems provide a variety of benefits to the human driver, they might introduce some human factor issues; at times, even small human factor issues might be associated with a serious car crash. It is assumed that human factor errors such as human trust, system acceptance, behaviour adaptation, situation awareness, and main agent to the control may be regarded as negative effects of automated driving systems [3]. Thus, a human driver can drive a highly automated system vehicle by oneself. At this time, it is important to consider how these systems effectively inform human drivers regarding situation awareness.

2 Situation Awareness

2.1 General Definition

Endsley stated that ‘situation awareness is being aware of what is happening around you and understanding what that information means to you now and in the future’ [7]. The formal definition of situation awareness can be divided into three separate levels:

Level 1: perception of the elements in the environment;
Level 2: comprehension of the current situation;
Level 3: projection of future status.

Level 1 indicates that the driver perceives the status, attributes, and dynamics of relevant elements in his/her environment (Endsley [7]). Information can be processed through human sensory perception by way of visual, auditory, and/or tactile functions. In Level 2, the driver understands what the perceived data and cues mean in relation to relevant goals. At this level, the driver should understand how the situational information influences safe driving to a specific destination. In Level 3, the driver predicts elements perceived during previous levels that may be relevant in the future. This projection leads the driver to proactively make decisions when events arise.

2.2 Situation Awareness in Autonomous Driving

Situation awareness is a critical factor of a driver’s ability to make decisions to avoid hazards, plan routes, and maintain safe travel. With the advent of automation, many current techniques used to assess driver performance, workload, or behaviour become useful only after a transition from autonomous to manual driving has occurred [8, 9, 14, 16]. However, situation awareness is also important to assess prior to transition due to concerns about driver performance. Such awareness can also be an indicator of an individual’s trust in automation and will hence be an increasingly important element in future automotive studies. In addition, according to Endsley, the development of autonomous vehicles can reveal three major problems [8]: firstly, poor vigilance when humans become monitors, often coupled with increased trust or over-reliance on the automation; secondly, limited information regarding the behaviour of the automation, relevant system, and environment due to either intentional or unintentional design decisions; thirdly, a reduced level of cognitive engagement that originates from one being a passive rather than an active processor of information. The autonomous driving system is not perfect; thus, if any problems occur that disable the driver and autonomous system from maintaining safe driving, a serious car crash becomes a possibility. Therefore, this paper suggests that the hexagonal spindle model be employed for human situation awareness during autonomous driving. The general version of situation awareness typically provides three levels of situations: perception, comprehension, and projection (Endsley [6]). Along the aspect of driving, human drivers should perceive any signs that induce irregular situations. Then, the human driver should understand the signs' meanings. Lastly, the human driver should expect which situations will soon occur. Those three levels are general descriptions of situation awareness as provided by Endsley [6]. On the other hand, it is necessary that drivers examine various factors occurring during autonomous driving in order to discuss situation awareness within the cognitive engineering aspect because autonomous driving should consider all safe driving aspects to get the driver to his/her destination effectively. Furthermore, each situation that occurs during autonomous driving should be connected and considered in regard to safe driving.

2.3 SPIDER Framework

In order to analyse situation awareness, the mental model of the driving environment should be considered (e.g., Durso et al. and Endsley [4, 6]). Many researchers suggest that working memory is regarded as a significant element of the driver's situation awareness (e.g., Jo-hannsdottir and Herdman [10]). According to Strayer et al., driving is related to several cognitive processes, as it requires that the driver visually scan the driving environment, predict where potential hazards might appear if they are not already visible, identify hazards and objects in the driving environment, decide which action is necessary and when it should be executed, and execute proper responses [15]. Strayer et al. named those cognitive processes SPIDER [15] and suggested that situation awareness is notified and updated through the SPIDER processes, which include scanning, predicting, and identifying [15]. Strayer et al.'s SPIDER framework involves Endsley's three levels of situation awareness [15]. Scanning is similar to Level 1 of situation awareness (perception of environmental elements), predicting is connected to Level 3 of situation awareness (projection of future status), and identification is connected to Level 2 of situation awareness (comprehension of current situation). In addition, the level of situation awareness influences the driver's responses. According to Strayer et al., there is even a small decrease in likelihood that a driver will successfully complete a SPIDER-related activity, which may influence the driver's situation awareness and driving performance [15]. Thus, even small errors in situation awareness can induce poor performance (Endsley [6]).

3 Previous Hexagonal Model

3.1 Benedyk's Model

The hexagonal spindle model was originally suggested by Benedyk et al. in order to clearly consider design activity based on personal, organisational, and contextual sectors within education areas [2]. Benedyk et al.'s paper suggested that, from an ergonomic perspective, learning—as the transformation and extension of the learner's knowledge and/or skills—can be regarded as work. Its 'workplace' is the educational environment in which the learning tasks are performed, and the 'learning work' is composed of a series of learning tasks [2]. The model of Benedyk et al. was designed based on a concentric ring model of ergonomics (informed by Kao's earlier model) to propose a new model for educational ergonomics: the hexagonal spindle model [2]. Different from Kao's model (1976), Benedyk et al.'s model involves the concept of time—as a spindle for serial and simultaneous tasks—and space shared by multiple learners that highlights areas wherein conflicts may occur [2]. The authors proposed a generic, high-level, holistic model of educational ergonomics that could influence the design of more effective learning environments. They also anticipated that its generic nature and transferability would encourage its use for the design and evaluation of different forms of learning materials, aids, devices, and environments with consideration of the requirements of different types of learners and learning tasks [2] (Fig. 1).

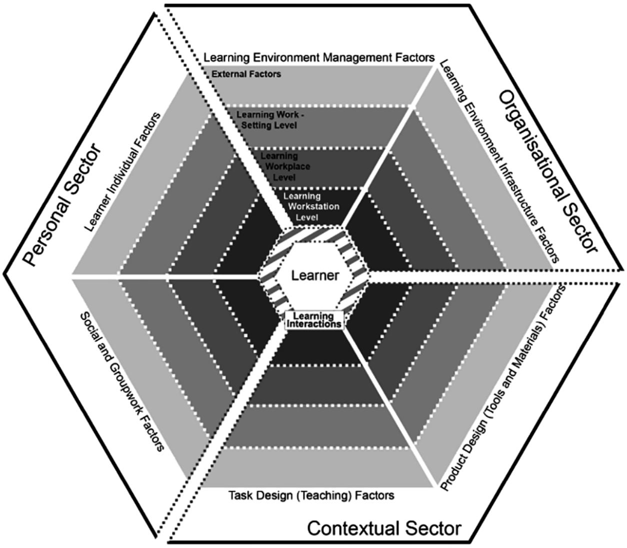

Fig. 1. A hexagonal spindle model for education from Benedyk et al. (2009)

4 New Hexagonal Model for Human Situation Awareness

4.1 Cognitive Engineering Approach

The cognitive engineering approach is considered in order for the new hexagonal model to describe human situation awareness. The general concept of cognitive engineering concerns the analysis, design, and evaluation of complex sociotechnical systems (Vincente and Wickens [16, 18]). Such sociotechnical systems are composed of several layers, and traditionally, many disciplines have viewed their technical cores as comprising the whole system [16]. The reason the cognitive engineering approach is applied to the new hexagonal model is that driving tasks require complex types of cognitive and environmental constraints. We additionally believe that, if the autonomous driving system is properly developed, complex situation information should be effectively conveyed to the driver. Such information processing involves many factors that influence the driver's driving strategy. Many different types of work analysis techniques that have been proposed should be categorised such that they may be used effectively. Rasmussen suggested three generic models that can be applied to group together work analysis techniques into *normative*, *descriptive*, and *formative* models [13]. Normative models describe how a system should behave, descriptive models depict how a system behaves in practice, and formative models clarify the requirements that must be satisfied. The new hexagonal model can be categorised as a normative model since the model describes how the situation awareness system conveys situation information to the driver in each layer.

Unlike the model introduced by Benedyk et al. (2009), this paper presents the hexagonal spindle model's different approaches toward applying situation awareness in autonomous driving. The new hexagonal model's shape refers to Benedyk et al.'s (2009) model, which comprises several combined layers and partitions that consider the environment within the various dimensions. In order to consider various factors and situations during autonomous driving, the hexagonal spindle model for human situation awareness has been suggested (Fig. 2). Similar to education areas, this paper suggests the following four sectors that may be applied to the hexagonal spindle model: vehicle sector, traffic sector, navigation sector, and other vehicle sector. Each sector possesses five situation awareness levels referred to in Strayer's study [15]: scanning, predicting, identifying, deciding, and executing. According to Strayer, driving is dependent upon several cognitive processes, which may include visually scanning the driving environment for indications of irregular events, predicting and expecting where potentially unsafe events might materialise if they are not already visible, identifying events and objects in the driving environment when they are in the field of view, deciding whether and which action is necessary, and executing appropriate responses [15]. Strayer defined those six cognitive processes while driving as SPIDER cognitive processes (scanning, predicting, identifying, deciding, executing, and responding) [15]. However, this paper proposes a model for human situation awareness during autonomous driving. Thus, if emergency situations suddenly occur, 'responding' may be the autonomous system's responsibility rather than the human driver's. Thus, the responding process was not included in the hexagonal spindle model for human situation awareness during autonomous driving.

4.2 Four Divisions of Sectors

In general, the hexagonal spindle model can be divided into the abovementioned four sectors to analyse human situation awareness while driving a vehicle with an autonomous system. In the vehicle sector, there are many types of vehicle controls, such as a steering wheel, throttle, brake, mirrors, and even the infotainment system. The human driver should control various devices and perform tasks according to each situation to change his/her driving strategy Controlling steering wheel, accelerator, and brake regarded as primary driving tasks that changed simultaneously as change of situation awareness. In the traffic sector, there exist various external factors, such as accidents, heavy traffic, road environments, and weather, among others, that influence human situation awareness. For example, if an accident occurs ahead, heavy traffic may follow behind, and the driver should revise his/her driving strategy to drive the vehicle

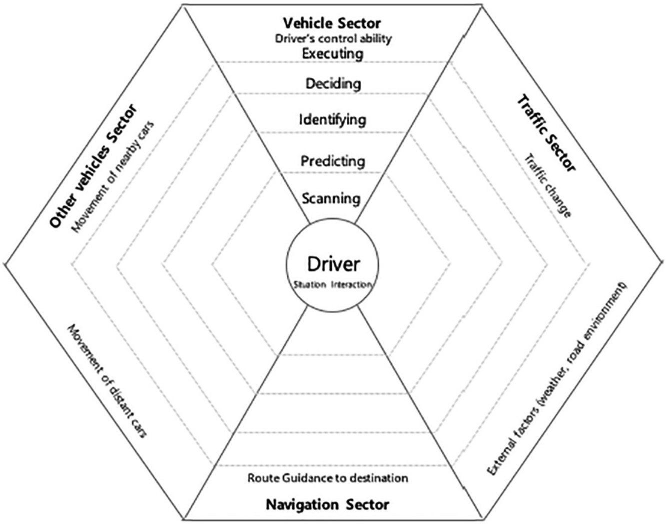

Fig. 2. A hexagonal spindle model for human situation awareness

effectively and safely. In the other vehicle sector, the movement of both nearby and distant cars can influence the driving strategy. Finally, navigation—considered part of the manual control—is an important factor of driving strategy, as route guidance to a destination can be changed according to changes in the traffic sector and the other vehicle sector.

4.3 Five Levels of Cognitive Task in Each Sector

Each sector comprises five layers that constitute a modified version of Strayer's cognitive processes [15]. Essentially, Strayer proposed six levels of cognitive process regarding situation awareness [15]. In this model, we regarded Strayer's cognitive process as tasks within layers [15]. Initially, a human drives a vehicle within his/her own driving scenario. During the first stage, the driver must scan the situation information regarding the driving scenario. If something happens, the autonomous driving system scans the situation information and informs the driver about what is happening. During the second stage, the autonomous driving system calculates any hazards or issues based on the previous data and scanned information. Thus, the driver can easily predict the volume of hazards and/or issues. During the third stage, the system informs the driver about related information to assist his/her decision making, and the driver can consider his/her driving strategy based on information provided by the system. During the fourth stage, the human driver decides whether to drive the vehicle effectively, safely, or economically (i.e., driving strategy). During the fifth stage, the driver executes several actions according to his/her driving strategy to avoid any events scanned during the first stage (Table 1).

Table 1. Five situation awareness levels

Segment	Objectivities
Scanning	Scan situation regarding driving scenario
Predicting	Predict hazards or issues related to driving scenario
Identifying	Identify road environment related to driving scenario
Deciding	Decide when the driver completes the driving strategy
Executing	Execute the driving strategy

4.4 Interaction with Situation

Figure 3 indicates several separate hexagons connected to one another. Each hexagon is regarded as a separate situation that can be connected according to the context of each situation. For example, if a car accident occurs ahead, cars behind the accident begin driving slowly, which influences traffic negatively. Therefore, each situation should be connected and considered together. The purpose of this paper is to provide a framework that considers and designs human situation awareness during autonomous driving. Thus, each situation can be analysed in detail, and a human decision model can be developed. Furthermore, each analysed situation can be linked in a specific sequence.

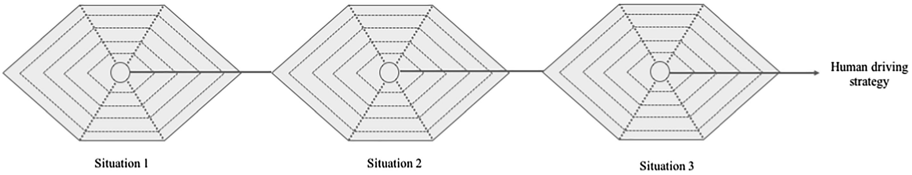

Fig. 3. Each spindle regarded as separate situation

5 Application of the Model

5.1 How the Model Can Be Applied

Table 2 indicates the detailed context for each model's sectors and levels that should be considered for efficient human situation awareness within driving environments. Each sector can be regarded as a driving environment, and the event occurring in each sector should be considered a different level of cognitive process. Each sector constitutes a driving environment involving several cognitive tasks that can be divided into various levels of situation awareness and considered when certain types of situations occur. According to Vincente and Rasmussen, events in complex human machine systems can be categorised according to their degree of novelty as familiar events, unfamiliar/anticipated events, or unfamiliar/unanticipated events [17]. Firstly, a familiar event is regarded as a routine in that operators encounter it frequently. Secondly, an unfamiliar/anticipated event can be described as only occurring infrequently, although the operator can expect how it progresses and then easily determine a solution. Thirdly, an unfamiliar/unanticipated event is also unfamiliar to operators because it rarely occurs. Unlike the second event, the third is not anticipated by designers, and hence, it is not possible for operators to rely on their own solutions—they must improvise instead [17]. Therefore, if a situation occurs while driving, the intelligent system can provide situation information specifically for each type of event, meaning information within each sector's cognitive task should be provided to the driver at the proper time. Thus, the system designer can use the model to consider how information should be designed to handle the various situations that may occur while driving.

Table 2. Contents of each section of the model

Segment	Vehicle sector	Other vehicle sector	Traffic sector	Navigation sector
Scanning	Scan situation awareness around driving vehicle	Scan situation awareness around other vehicle (nearby own vehicle)	Scan situation awareness about traffic (sudden accident ahead, traffic jam, road status etc.)	Scan the current navigation route
Predicting	Predict hazards or issues which might come to the vehicle	Predict hazards or issues which might come from the other vehicle (nearby own vehicle)	Predict hazards or issues which might come from the traffic change	Predict hazards or issues which might come on the navigation route
Identifying	Identify road environment around vehicle what is happening	Identify road environment around the other vehicle what is happening (nearby own vehicle)	Identify hazards or issues which might come from the traffic change	Identify hazards or issues which might come on the navigation route
Deciding	Decide driver's action to avoid hazards or issues for safe driving	Decide driver's action to avoid hazards or issues for safe driving	Decide driver's action to avoid hazards or issues for safe driving	Decide driver's action to change route to avoid hazards or issues for safe driving
Executing	Execute driver's action to avoid hazards or issues for safe driving	Execute driver's action to avoid hazards or issues for safe driving	Execute driver's action to avoid hazards or issues for safe driving	Execute driver's action to change the route to avoid hazards or issues for safe driving

In addition, the designer can consider the abstraction level of information according to each situation. This model is expected to help apply the concept of the ecological interface design when the designer creates situation awareness support systems. According to Vincente and Rasmussen, the *ecological interface design* is a kind of framework that proposes a set of principles for designing interfaces that provide fundamental properties of human cognition using a specific method [17]. Thus, it can be expected that operators adapt to the complexity and events unanticipated during system design. Along the concept of ecological interface design, it is recommended that the environment be analysed with a holistic view before operators' work, tasks, and knowledge are analysed [17]. Thus, it is not easy to comprehend human behaviours without simultaneously understanding the environment in which operators work. Through this model, the designer considers the driving environment under the holistic view. Then, the designer deliberates what kind of information can be provided to the driver according to each situation in order to assist human situation awareness and avoid complexity of information.

Furthermore, information should be provided according to Rasmussen's SRK framework [12], which includes skills, rules, and knowledge taxonomy. The SRK framework depicts three qualitatively different ways in which operators interact with their environments [12]. Skill-based behaviours and direct behavioural interaction with the world occur without conscious control. Rule-based behaviours involve a sequence of subroutines and a familiar, worldly, perceptual cue with an action or intent without intervening cognitive processing. Knowledge-based behaviours include serial, analytical problem solving based on an analysis of the whole environment and a symbolic mental model [12]. If the SRK framework is applied during information provision, the designer can consider which information should be chosen and provided through the model.

6 Conclusion

In summary, although many automobile manufacturers concentrate on autonomous driving, some human situation awareness research has been recently conducted. The conveyance of information from the system to the human becomes an important issue in autonomous driving system. As autonomous driving systems develop, the situation that is collected from the system will be complex, and thus, conveying that information to the human driver is also difficult. Thus, situation information that can be conveyed from the system to the human driver should be considered under the holistic view in order to reduce the cognitive load and provide information at the proper time. This model was designed to consider the detailed cognitive process along the different perspectives when an unanticipated event occurs on the road. Through the model, the designer can consider four different sectors, five different levels of cognitive processes, and several interrelated situations whose relationships induce specific events. This model can be used to help analyse different situations of each event as well as how cognitive processes in each division are connected.

Therefore, this paper suggests that the hexagonal spindle model be employed for human situation awareness during autonomous driving. Through the model, it can be expected that HMI designers are capable of considering various aspects of human situation awareness in regard to autonomous driving to help the driver implement his/her own driving strategy when facing unanticipated events on the road.

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