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An Ecological Interface Design Approach for Developing Integrated and Advanced In-Vehicle Information System

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Abstract

The objective of this study is to propose a principled ecological interface design approach for in-vehicle information system and reduce driver's cognitive overload otherwise it might cause significant deterioration of driving performance and fatal consequences. Rasmussen's *abstraction hierarchy* was applied to analyze functional difference between the old and new cars. Information requirement analysis based on the *Skill-Rule-Knowledge framework* was conducted to classify the level of driver's cognitive load when interacting with modern car functions. It was found that driving assistance functions have been increased but their interfaces are not integrated nor standardized properly yet. Sometimes information is too much, too complex or not given at the right time. This study suggests to follow four principles of design for improving current in-vehicle information system: 1) *Consolidation and Parsimony*; 2) *Abstraction and Integration*; 3) *Utilization of different display characteristics*; 4) *Standardization through Customization*. In this way of information design and distribution, people having different levels of driving experience would easily interact with new powerful functions of the car and stay in a safe, comfortable driving environment without losing connectivity.

Keywords: Cognitive Overload, Driving Experience, Ecological Interface Design (EID), In-Vehicle Information System (IVIS), Information Abstraction, Principles of Design

1. Introduction

Recent drivers do not cope with the same tasks and environment of several years ago, when the car was considered as a mechanical system which simply provides means of transportation from one point to another. In these days a vehicle should provide information to the driver regarding safety, comfort, connectivity, among other functions, therefore cars are becoming intelligent information systems[1].

In the recent years of becoming an information and knowledge society, new IT technologies have been developed such as microprocessors, electronic displays, sensors, touch screens, and mobile networks between others. With such technology new possibilities have been opened wide to automobile manufacturers to provide information for the driver. IVIS change the way drivers interact with their automobiles substantially[2]. Unfortunately, the focus of developing automotive information technology so far has been that of adding new functions with independent interfaces. That is why the driver can feel uneasy to operate the new system and even get duplicate information from different displays.

IVIS is not a new concept since even early automobiles had analogue displays in forms of dials and gauges to provide relevant information about the vehicle and its surrounding environment. What has changed since the early days is the quantity and quality of information with different physical forms and formats that drivers are receiving at any given time. With this background, it can be assured that in these days, automobiles have become a complex human machine system with a particular complexity: "Driving demand decisions that are made in seconds, compared to other domains where decision are made over minutes"[3].

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Reducing the overload of information in the IVIS becomes imperative because this excess may distract the driver and thus deteriorate his driving performance if otherwise[4].

Information systems may contribute to distraction and could become a hazard if they are not designed to be compatible with driving[5]. Therefore, IVIS must be an aid to drivers and not a supplier of distraction while performing their main task, driving.

The information must be presented so long as it is of significance aid to the driver and considering the current driving situation in which he is at the moment. Without a principled approach, it is hard to design the IVIS ensuring that they support the operator to drive safely while enjoying the route, without a decline in the driver's cognitive resources and distracting him from his main task which is to operate the automobile safely[6,7].

The logical question then is: How can we design IVIS in a way that integrates existing functions based on driver needs and thus make a complex human machine system easier to operate?

One way it could be done is by applying the principles of User-Centered Design (UCD). As Burns and Hajdukiewicz stated on their book, UCD results have been very successful when the job is done by programmers with extra training in psychology[8].

The strategy adopted in this paper is a framework called Ecological Interface Design (EID) that is an approach of UCD and it has been applied to deal with complex systems[9–13].

In their paper "Ecological Interface Design: Theoretical Foundations" written by Vicente K.J. and Rasmussen J., the authors developed this framework while analyzing Nuclear Power Plants control rooms. What they found was that unfamiliar and unanticipated events pose a threat to system safety[14].

EID has also been applied in different studies to address information systems including IVIS with mixed results[3,11,15–19]. One of the strong motivations of this study came from a conclusion of other research, "Robust performance across situations may be a more critical design consideration than relatively high performance in a single situation." made by Lee et al. In their study they used an experimental apparatus to simulate a car mirror for testing driver responses in terms of accuracy and time[3].

The purpose of this study is to make clear that there is cognitive overload in the current IVIS and propose a principled approach to solve this issue. To validate the assertion, this study is focused on analyzing the quantity and quality of visual information displayed in three ways: head-up (HUD), head-down (HDD) and multi-function displays (MFD).

Based on these results, an EID approach for improving IVIS design is followed to propose a new strategy to distribute information with particular priorities throughout different displays. It is also suggested how to integrate lower level information gathered from individual IVIS components into high level information in more comprehensible ways.

This study is developed in 3 stages.

At first, Work Domain Analysis (WDA) and Information Requirement Analysis (IRA) are performed to understand the current situation and constraints of the system.

Next, current IVIS displays is analyzed to understand how they are arranged and what deficiencies they have. The scope of this study is on the information displayed in the 3 kinds of visual displays previously mentioned.

Then finally based on those analysis, IVIS design principles based on EID are proposed to arrange information in an integrated and advanced way.

2. Backgrounds

2.1 Ecological Interface Design (EID)

Ecological Interface Design (EID) reveals to the users the environment and its relevant constraints by providing the information necessary for routine operations and also unanticipated situations[17]. Thus EID has particular potential for being applied in the IVIS since many car accidents happen because one or more of the drivers failed to recognize and act according to a critical system constraint[20].

This is why EID is proposed as the framework to redesign IVIS in this study and also because there are some key times when this approach is particularly useful as follows[8]:

1. *When asking users does not work:* Each driver has their own driving experience and particular preferences about the information they want to get in order to operate the system. If we identify the constraints before getting user input, we can reduce the scope of possible solutions to those that are really valuable.
2. *When we want users to become experts:* It is obvious that accidents occur more likely when users are less experienced with the system they are operating.

Therefore, making this learning process shorter for new drivers would result in fewer accidents and thus safer and more comfortable driving.

3. *When we want to handle the unexpected:* Driving is an activity that is highly complex and also unpredictable because it has high influence of human operators.

EID has mainly two conceptual foundations. One is the Abstraction Hierarchy (AH) that is a tool of Work Domain Analysis (WDA) and the other is the SRK framework which is used to conduct Information Requirement Analysis (IRA) at a cognitive level[11,14]. The goal of the WDA is to expose the system constraints, purpose, required functions and information. The IRA is performed in order to determine what interaction is needed in form of information flow between the components of the Human Machine System. With relevant transactions of information between the components, the task and functions will be performed as smoothly as possible[10].

As Vicente K.J. and Rasmussen J. concluded in their EID paper, "abstraction hierarchy is a useful way to represent a work domain". Abstraction is basically splitting a complex system into simpler parts. It was also proven by Rasmussen that expert troubleshooters navigate through an abstraction-decomposition space as they solve problems[14].

The AH generally has 5 levels and all or some of these levels can be performed depending on the type of system and scope of the study. The AH starts with "What problem do we want to solve?" which is the first level of abstraction: *Functional Purpose*. Then by asking "how?" in a progressive way we can move to the different levels. This second level is the *Abstract Function* which is the way through the system can achieve its functional purpose. The third level deals with the processes that are part of the abstract function, and is called as the *Generalized Function*. Then based on that processes, equipment is needed (fourth level: *Physical Function*) and this equipment needs certain design (fifth level: *Physical Form*)[1].

Vicente and Rasmussen explained that a goal of interface design relying in SRK framework would be to "Design interfaces that do not force cognitive control to a higher level than the demands of the task require, but also provide the appropriate support for all three levels"[14].

The SRK framework states that there are three different levels of behaviors or cognitive processes performed by operators while interacting with the system[21]:

1. Skill Based: Almost no conscious control to perform an action. (Lowest level of cognitive control)
2. Rule Based: Use rules or procedures to perform an action or actions in a familiar work situation.
3. Knowledge Based: An advanced level of reasoning is required in order to perform an action or actions. This is usually a novel and unexpected situation. (Highest level of cognitive control)

To make the SRK framework clearer, Figure 1 shows the different stages of information processing that the operator has to perform in each type of cognitive behav-

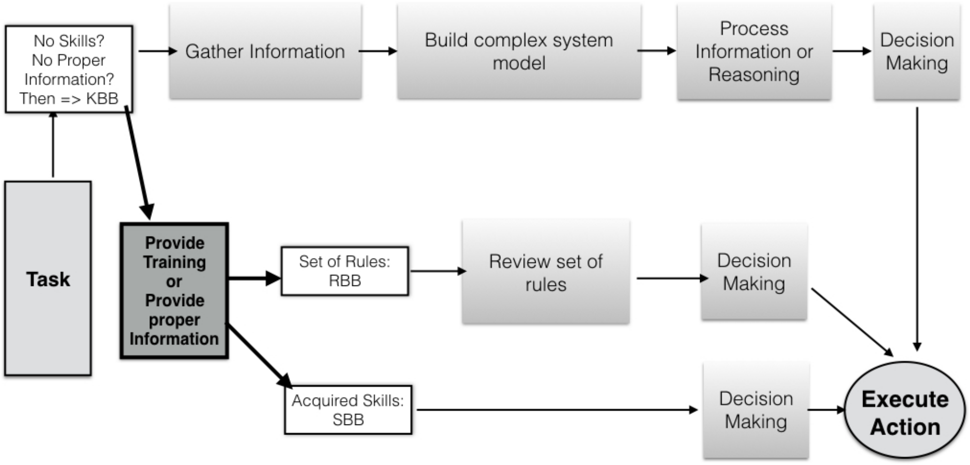

Figure 1. SRK framework: concept.

ior. Since SBB has less steps before executing the action, this level should be used the most in order to reduce mental workload. However, the other levels should also be taken into consideration and appropriately supported.

2.2 Different Types of IVIS Displays

In current IVIS, drivers do not interact only with visual modality, but visual displays were selected as the domain of this study since they are the ones that are more crowded with stimuli for the driver and mainly because the visual sense is the single most important sense in driving.

The state of the three different types of visual displays that IVIS use in current days is as follows[22]:

1. Head-Up Display (HUD): Is a transparent form of display that superimposes information on the window shields without requiring the operator to look away from their usual viewpoint. It was originally used in military aviation but now it is used in more commercial applications including vehicles.
2. Head-Down Display (HDD): Is the medium through which information has been traditionally presented in the cars. It is usually located behind the steering wheel. This kind of display requires the driver to take his eyes off the road. It is also called as instrument cluster, multi-information display, and dashboard; but for the purpose of this study it will be referred to as HDD.
3. Multi-Function Display (MFD): Is generally a LCD screen that let show information to the user in different ways. This is usually where the Audio, Video and Navigation (AVN) functions are displayed now. Due to its digitally controllable features (customizability), this type of display is used most commonly as a Graphic User Interface (GUI) for the functions that require direct interaction or that have various layers of operation. It is also called as infotainment system display, navigation system displays, and auxiliary display; but for the purpose of this study it will be referred to as MFD.

The strengths and weaknesses of the three different displays are shown on Figure 2.

3. Results

3.1 EID

3.1.1 Work Domain Analysis - Abstraction Hierarchy

The WDA is conducted to understand the vehicle as a Human Machine System (HMS) by mapping its functions, environment, information requirements and interactions.

The functions of the system were identified using AH until the level on which the average driver operates directly with the car. For example, in the airbag system the driver only needs to know whether the function is at its normal state. But in the acceleration function the driver has to know the level of speed required and whether if he needs to increase or decrease the current level of speed.

The results from the AH of the car HMS is presented in Figure 3. If the complete HMS is analyzed deep in detail, the AH would be really wide. However, Figure 3 would be enough for the purpose of this study which is to understand the current functions as they impact the operator and the interactions needed in order for the HMS to achieve its goal.

Without much reasoning it is obvious that the functions of cars these days differ from those in the past. To make this evident, another AH figure (Figure 4) is shown for pointing out the functions that did not exist before the cars turned into Intelligent Information Systems.

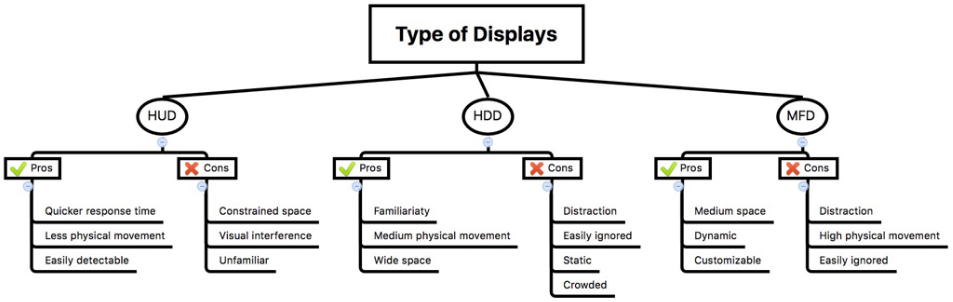

Figure 2. Types of visual displays—pros and cons.

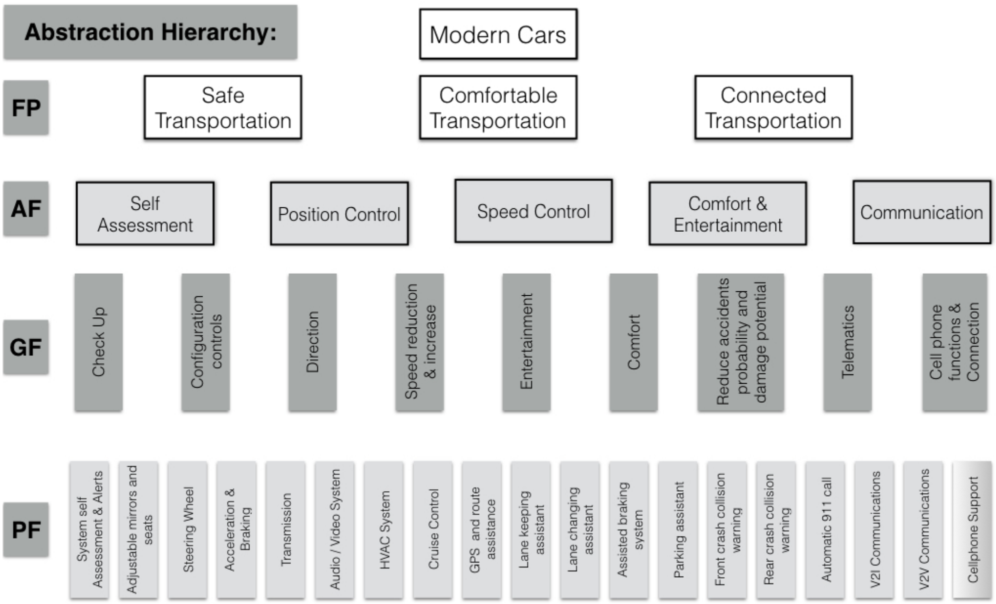

Figure 3. Abstraction hierarchy of the modern cars.

The first level (the levels in AH are read from top to bottom) of abstraction is the 'Functional Purpose', or goal of the system; in this study it was considered that cars in these days have 3 functional purposes. *Connected transportation* is considered as a new one in addition to the other 2 classic ones: *Safe transportation* and *Comfortable transportation*. This means that drivers want to get from point A to point B safely and comfortably without losing connectivity.

The second level is the 'Abstract Function (AF)'. Functions at this level of abstraction were considered as the groups of functions with which the system can enable its functional purpose. Each one of them may aid to one or more functional purpose.

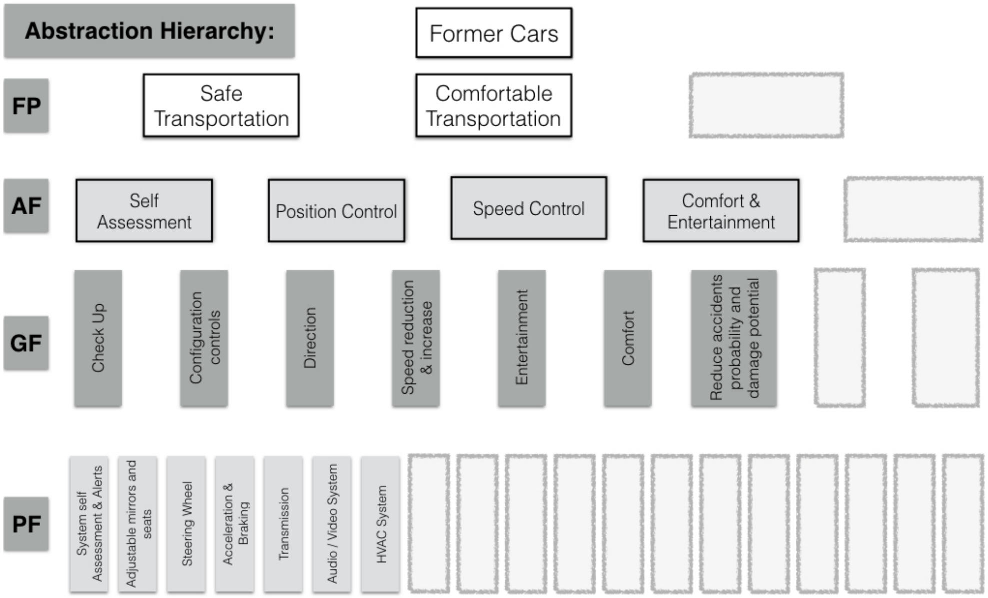

Figure 4. Abstraction hierarchy of the former cars.

Self Assessment represents the group of functions ensuring that the system is ready to be used by a particular driver. *Position control* refers to the actions that will aid the car to change its current location. *Speed control* is the means with which the car changes its state of motion. *Comfort & Entertainment* consists of the functions that will make the driver emotional state remains as pleasant as possible during the trip. *Communication* goal is to allow the driver and system stay connected with other vehicles, infrastructure, friends, and business, among others.

The group of abstract functions has remained the same as in the previous days with the only difference being the *Communication Function*, which was added in very recent years.

The third level of the AH is 'the Generalized Function', in this study it is constructed by grouping functions with the same AF as a goal. But these generalized functions are not directly operated by the driver as they are not one real function but instead an abstraction of the system to make it more comprehensible to the reader.

The *Check Ups* include all the functions, sensors and alert systems used by the car to point out to the driver if the system is in its desired functional state or not. The *Configuration Controls* include all the movable parts of the car that are meant to be configured by each driver to ensure a proper usability of the vehicle, this include seats and mirrors. *Directions* are the operations needed to head the vehicle to its required route. *Speed reduction & increases* refer to the means with which the velocity of the vehicle is changed. E*ntertainments* are the functions with which the driver can be pleased in the trajectory from point A to point B. *Comforts* are the set of functions to ensure that the driver enjoys a smooth trip with minimum discomfort. *Reduce accidents probability & damage potential* functions are in charge of minimizing injuries to the driver in case of an incident. *Telematics* are the new functions that allow a car to communicate with other vehicles and infrastructure in order to gather and use data to make the ride as comfortable and as safe as possible thus making the car an Intelligent Transportation System. *Cell Phone functions & connections* are the support system that drivers will use to continue using all the main cellphone built in functions while driving.

As it is shown in the Figure 4, this level of functions has not been changed in a significant manner. Only the *Telematics* and *Cellphone* functions have been added to obtain the connectivity of the system.

The fourth level is 'the Physical Function' which has 20 physical functions considered in this study. It is noted that the interaction between human and machine really happens at this level. That means properly designed interfaces are needed in this level to present all the relevant information for the driver to get situation awareness, make right decisions, and choose exact controls and actions to achieve its purpose.

Once again, the driver uses car to change his current position toward the destination safely and comfortably without losing connectivity. In order to do that he has to use his own skills and knowledge and also take advantage of the physical functions of the car (that were described with the AH). The actions performed by the driver are called tasks to distinguish them from the functions performed by the system. Driving is a task that has many situations and conditions and therefore many subtasks.

It is clearly shown by comparing the two AH figures that most of the functional changes have been made at this level in a way of adding new physical functions. In the old days 7 physical functions were built on the car comparing to those 12 out of 19 functions that are newly added up in the recent cars resulting in an increase of 171% of functions in the car. This means that driver's tasks have been reduced by using these newly added functions but it also means that the number of interactions between human and machine have risen.

The fifth level is the Physical Form which is not explicitly mentioned in the AH figures. Nonetheless this level was considered in the study and more detailed analysis of the physical form focusing on the 3 types of displays will be shown on section 3.2.

3.1.2 Information Requirement Analysis and SRK Framework

Based on the physical functions exposed in the previous section, an Information Requirement Analysis is performed to show the information flows between the components of the HMS. It explains how a cognitive process is made by the driver and where the more margin for human error is.

When a task is performed by interacting with the system functions, the driver has to get information or raw data from two main sources; his own senses and processing capabilities or the information displayed through the interface of the vehicle (physical functions and forms). This information presented through different displays would be more or less abstracted. Depending on this level of abstraction and processing that the driver has to execute, the driver will engage in any of the three levels of cognitive behavior: SBB, RBB or KBB.

Experience also plays an important role here, since experienced drivers will usually engage in lower levels of cognitive process. It is due to the fact that experienced drivers already have sufficient knowledge with which they can compare on the ad hoc situation.

After the decision has been made the driver has to execute the action he just chose to do. Figure 5 shows an exemplary course of information processing that the driver has to face in order for executing a lane change.

What can be extracted from this analysis is that if the information is processed relevantly and showed in a way that can help the driver to engage in lower levels of cognitive processing, he would reduce the mental workload that can be used for some other tasks.

As it has been shown cars nowadays differ mainly on the *physical functions,* this is why an IRA of these modern technologies was performed in order to determine the amount of processing that the driver has to make for taking advantage of these tools. Among the 12 new *physical functions* that modern cars have in these days, 8 functions that are not fully automated still require human interaction.

For these 8 functions, the behavior of the drivers while interacting with the system were analyzed in terms of SRK framework. If the driver has to perform some level of complex information processing it was considered as KBB. If the driver can get most of the information required to perform a task from the system display it is considered as RBB. And if the driver can get all of the information from the display and knows exactly what has to be done right after getting the information it is considered as SBB.

To make clear this approach for classifying the behaviors, the *Parking Assistant System* (PAS) is analyzed in detail as an example. If the PAS gives only the images from a rearview camera, the task of the driver is considered KBB since the driver would have to analyze the distance that the cars have between each other and the direction needed to park properly. What the *PAS* does in this design is that it relieves the driver of the motions to acquire information and they become in a more comfortable of obtaining this data but it is not processed or abstracted. The *PAS* that becomes a RBB support is the one that provides guidelines in addition to the image of the rear camera displayed in monitor so the driver can then adjust his steering wheel and see in real time if he is in the proper direction or need to adjust car's trajectory (Figure 6). An SBB support would be the *PAS* that could provide the driver more comprehensible information in addition to the features of the RBB support, so he can reduce his amount of processing and just rely on his skills. For example, let's consider the auditory signals that indicate the driver when he is getting close to the surroundings; in this way the driver receives an integrated visual information about the proper direction with audible information about the distance to the obstacles; by using this type of assistance, the driver only needs to be skillful about moving the car in the right direction.

Thus it means that one same task could have more than one cognitive behavior control from the driver based solely on the information displayed. Therefore,

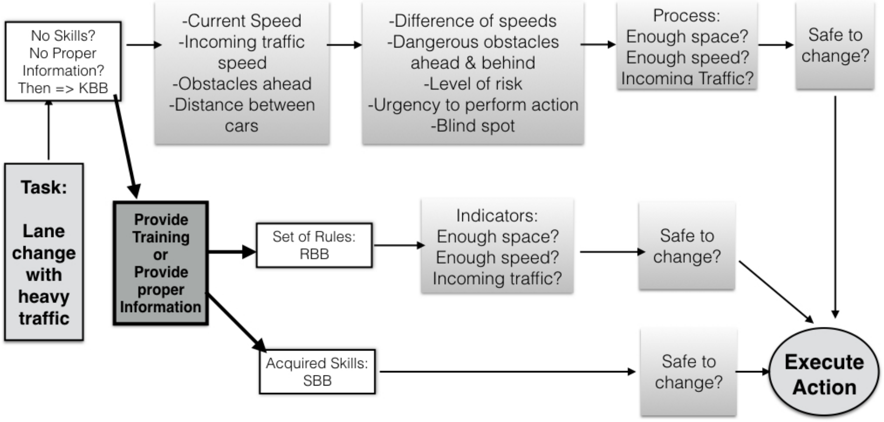

Figure 5. SRK framework: lane change example.

Figure 6. Example of parking assistant function display without and with guidelines.

following SRK framework the attention should be directed to develop a more integrated system to gather information and present it in a fully processed and comprehensible format.

If novice drivers are supported during their initial months of driving, proper IVIS design following SRK framework principles could result in significant reduction of accidents as it is a known statistic that most car accidents involve young or inexperienced drivers. The same can be applied for senior drivers whose reflexes and processing capabilities are reduced[23,24].

Table 1 and Figure 7 summarize the results from the SRK analyses applied on the new 8 functions. It was found from the results that 75% of the new 8 functions that require human interaction still require RBB and KBB from the driver in order to execute the task. What some IVIS functions do these days is that they act as indicators or binary warnings which provide little information rather than graded ones. Thus the further processing and decision making is still needed to be performed by the driver.

Table 1. Classification of the new physical functions based on SRK framework

Functions	Task Associated	Novice Driver Information Processing	SRK
Lane Changing Assistant	Change Lane	Decide: Is relative speed enough? How much should the speed be increased/reduced? Are the obstacles around me avoidable?	KBB
Front Crash Collision Warning	Accelerating, Braking. Changing Direction	Decide: Is relative speed enough? How much should the speed be increased/reduced? Are the obstacles around me avoidable?	KBB
Rear Crash Collision Warning	Accelerating, Braking. Changing Direction	Decide: Is relative speed enough? How much should the speed be increased/reduced? Are the obstacles around me avoidable?	KBB
Parking Assistant (Not automated, guidelines assisted)	Park the car	Rules: Is the space enough for the car? Do the guidelines get me in position or should I adjust the trajectory?	RBB
Cruise Control	Accelerating, Braking. Fuel Efficiency	Rules: Required speed Need to change speed	RBB
Lane Keeping Assistant	Accelerating, Braking. Changing Direction	Rules: Alarm sounded No obstacles ahead	RBB
GPS and Route Assistance	Set and adjust destination. Change direction to get to destination	Set destination and follow instructions	SBB
Cellphone Support	Use cellphone	Use or not Use?	SBB

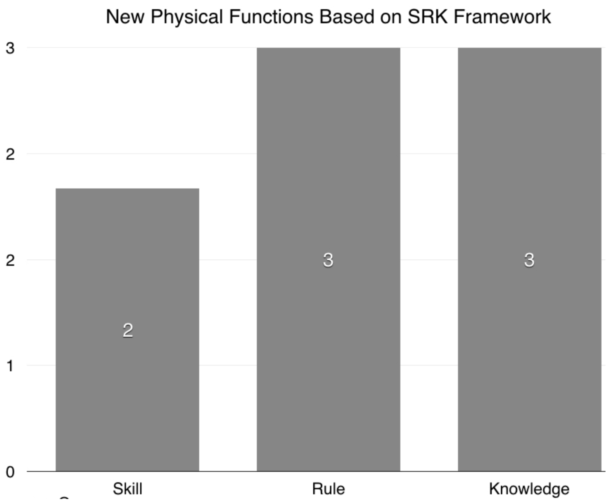

Figure 7. Classification chart of new physical functions based on SRK framework.

3.2 Information Distribution of Current IVIS

3.2.1 Timing and Frequency

To check out the strategies of information distribution adapted by different car manufactures, it is analyzed the forms and formats of information presented throughout the three different types of visual displays in the current IVIS. For this analysis, raw data was sampled from 3 models of cars made by different brands with smart IVIS technology and its source was official product manuals provided on the Internet by the car manufacturers.

The distribution of information currently being presented to the driver is summarized in Table 2. Since the car manufacturers use different names for their functions, an easier nomenclature is taken in this study. It is clearly found from the analysis that car manufacturers don't

Table 2. Information distribution matrix of different car manufacturers

Brand	Display	Information
M	HUD	N/A
	HDD	Speedometer, fuel gauge, tachometer, coolant temperature, low-beam head lamps, parking lamps, ESP, high-beam head lamps, electric parking brake, distance warning, turn signals, tire pressure monitor, restraint system, seat belt, diesel engine: pre-glow*, coolant, rear fog lamp, check engine, reserve fuel, ESP OFF, ABS, display {time, outside temperature, drive program, transmission position, shift recommendation, active parking assistant, cruise control, low range off-road gear, adaptive high beam assist, ECO start/stop, hold function, [trip menu (trip odometer and odometer) or trip from start (distance, time, average speed, average fuel consumption) or eco display (acceleration, constant, coasting) or range fuel consumption (range, fuel consumption) or digital speedometer (shift recommendation, speedometer) or navigation system menu (direction of travel, current road, next road, distance to change of direction <in number and graphic>, distance to destination, distance to the next change of direction, directions symbol, lane recommendation) or audio operation or video dvd operation or telephone menu or assistance menu (attention assist, lane keeping assist, distance warning, pre-safe brake, DSR, blind spot assist) or maintenance menu (tire pressure, service due date)}
	MFD	Map display, route calculation, audio operation, video operation, telephone menu.
B	HUD	Speed limits, navigation information, urgent warning signals, rpm, lane guiding, intersection zoom, cruise control, collision warning.
	HDD	Turn signals, speedometer, cruise control, tachometer, coolant temperature, current fuel temperature, display 1 (clock, external temperature, indicator/warning lamps, cruise control), display 2 (transmission position, Hill descent control, service due date, service requirements, odometer and trip odometer, high-beam assistant, fuel gauge, parking brake set, high-beam head lamps, low-beam head lamps, front fog lamps, lamp flashes, engine malfunction.
	MFD	cd/multimedia, radio, telephone, navigation, connected drive, vehicle info
L	HUD	Audio display, shift position, shift range, dynamic radar cruise, pre-collision system, turn by turn navigation, vehicle speed
	HDD	ECO lamp, SPORT lamp, speedometer, fuel gauge, odometer, trip meter, transmission position, coolant temperature, turn signals, high-beam headlamps, headlight indicator, tail light indicator, front fog light indicator, cruise control, radar cruise, intuitive parking assist, slip indicator, VSC off, Pre-collision system, BSM indicator, READY indicator, EV drive mode, ECO mode, SPORT mode, Hybrid SNOW, service requirements, display (energy monitor, current fuel consumption, average fuel consumption after refueling, average fuel consumption, average vehicle speed, cruising range, tire inflation pressure, outside temperature)
	MFD	Audio system, air conditioning system, telephone

share a principled approach for the information distribution. The same indicator is found on different displays depending on car brands. Let's look at the *RPM indicator* to begin with, in two brands it is shown in the HDD, but on the third brand it is found not only on the HDD but also on the HUD; the shift position indicator is shown on two brands in the HDD and on the third brand it is found duplicated in the HDD and the HUD; finally, if we review the *audio function* in one brand it is controlled through the MFD, in a second brand it is displayed in the HDD and MFD and on the third brand we can find it on the HUD and the MFD.

Table 3 summarizes the information distribution strategy currently used by car manufacturers. *Timing* means how often information is given on the displays; *constant* means that it is always appeared on the dis-

Table 3. Information distributions among the three different display types

Display	Information	Timing	Frequency
HUD	1. Speed	Constant	Low
	2. Turn by turn directions	Constant	High
	3. Current direction	Constant	Low
	4. Speed limit	Occasional	High
	5. Distance between cars	Occasional	High
	6. Lane keeping assistant system	Occasional	High
	7. Blind spot warning system	Occasional	High
HDD	1. Speed (A + D)	Constant	Low
	2. RPM	Constant	Low
	3. Current Gear	Constant	Low
	4. Mileage	Constant	Low
	5. Speed limit	Occasional	High
	6. Blind spot warning system	Occasional	High
	7. Oil pressure	Constant	Low
	8. Fuel	Constant	Low
	9. Tire pressure	Occasional	Low
	10. Engine temperature	Constant	Low
	11. Battery	Constant	Low
	12. Seatbelt	Occasional	High
	13. Engine problem	Occasional	Low
	14. Turn signal	Occasional	High
	15. High/low, fog lamp	Occasional	High
	16. Parking brake	Occasional	Low
	17. Time/date	Constant	Low
	18. Distance between cars	Occasional	High
	19. Lane keeping assistant system	Occasional	High
	20. Front & Rear Camera	Occasional	High
	21. Vehicle's door	Occasional	High
	22. Air Bag	Occasional	Low
	23. Current Direction	Constant	Low
	24. Distance & time left	Constant	Low

Table 3. Information distributions among the three different display types (*Continued*)

Display	Information	Timing	Frequency
MFD	1. Speed (D)	Constant	Low
	2. Distance & Time left to destination	Constant	Low
	3. Speed limit	Occasional	High
	4. Moving direction	Constant	Low
	5. Turn by turn directions	Constant	High
	6. Surrounding information	Occasional	Low
	7. Front & Rear camera	Occasional	High
	8. Collision warning	Occasional	High
	9. Radio / video system	Constant	High
	10. Cell Phone connection	Occasional	High
	11. Virtual assistant	Occasional	Low

play, usually in the form of analog displays (RPM, Speed meter), and *occasional* means that it is shown at a precise moment or on temporal basis. *Frequency* is how often the driver needs this information to achieve the *functional purpose* of the system. It is different with the real number of driver's access to the specific information, because the driver makes accesses to the information sometimes when it is not necessary and does not when it is indeed necessary. Whenever a driver needs the physical form of information at least once on each ride, that physical form is considered *high frequency*, if not it is *low frequency*. For example, speed meter is not required all the time by the driver. The operator only wants to know if his speed is adequate or not, however it is always shown in the HDD. In the previous days, drivers had to use the speed meter and then process if they were driving at the proper speed or not, cars nowadays have alarms that notice the driver when speed is not appropriate, this is why speed meter by itself is no longer required with such a high frequency. What happens now is that since the information is being constantly shown it becomes a distraction to the driver that eventually he will look and making it look like it is really required.

In Figure 8, C stands for *constant* and O for *occasional*. In a quantitative manner, 16 physical forms of information are showed in a *constant* way but with low *frequency* of use by the driver. In the other hand when the information is required with more *frequency* by the driver, they

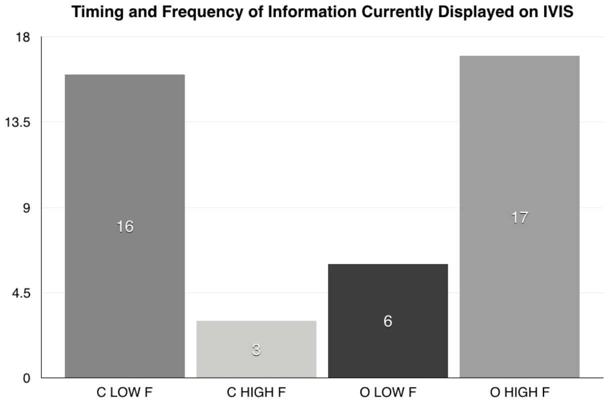

Figure 8. Timing and frequency of information currently displayed on IVIS.

are showed in an *occasional* mode. In broader terms 45% of physical forms are being showed in a *constant* basis to the driver.

3.2.2 Types of Display and Its Timing and Frequency

The distribution of information in each kind of display is depicted in Figures 9 and 10. On these figures we can find that the information is crowding on the HDD, 57% of the physical forms are showed through this display, followed by 26% of the MFD and 17% of the HUD. There is no significant difference in choosing the displays according to its timing (whether if the information is shown in an *occasional* or *constant* basis) nor frequency (whether if it is required by the driver in a *high* or *low frequency* rate). These results may mean that the car manufacturers do not take advantage of the different features of the displays summarized in the Figure 2.

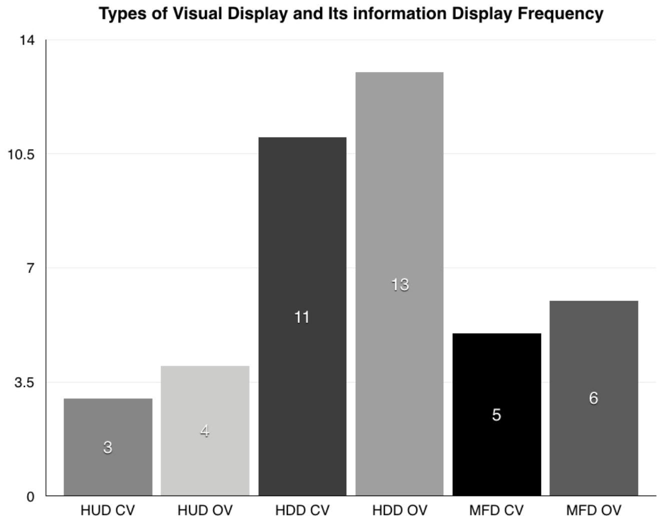

Figure 9. Types of visual display and its information display frequency.

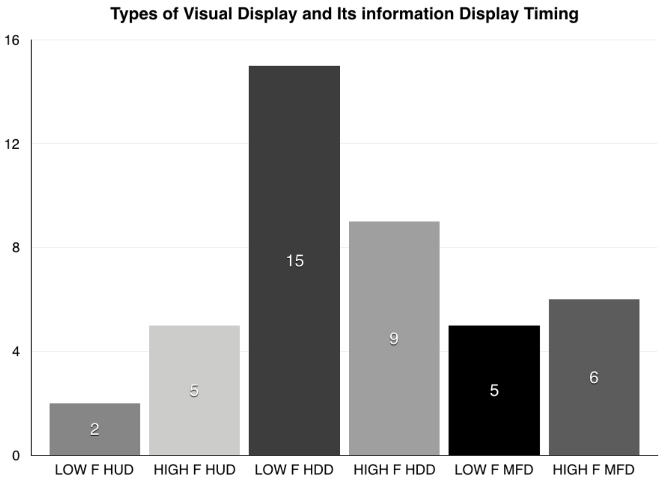

Figure 10. Types of visual display and its information display timing.

4. Discussion

4.1 Quantity of Information

On the basis of the AH performed in the previous section, it can be assured that the cars of then and now share most of the generalized functions to achieve its purpose with the exception of the *connected transportation* functions. What has changed most significantly is the level of physical functions and thus the cars in recent days are completely different at its physical level.

With the addition of the *Communication* elements it is accurate to say that cars have now become Intelligent Information Systems because there are autonomous functions to substitute certain tasks performed by the driver in the former days. Also with the V2V and V2I communications cars are getting information from the environment and opening the possibilities of having safer roads and smoother rides in the upcoming years.

As shown in the section 3.1.1, physical functions have increased in a 171% (from 7 to 19) compared to the former car. These functions were developed to reduce driver's cognitive load to realize the status of the system and to execute actions safely. They have met their goals by part but it is still not enough. This does not mean that the driver has to do more work now than before but the sources of data, interactions and information shown in the current displays have also increased.

Interactions between the human and the system are not bad by themselves; communication is necessary as it allows the system and the human to be in sync with their own activities. What is not good is that these interactions or this design of information that takes place in the interface if it is not designed by taking into consideration of the human processing capabilities.

Let's think about a complex situation; what would happen if the driver has a front collision warning when he tries to change lane and he also gets the blind spot alert or the rear collision warning; what should he do? Is it possible that the driver can be aware of the situation and its constraints in order to solve the problem with only binary warning signals? This kind of functions should be integrated such as to provide fully processed and valuable information in order for the driver to make a decision just with a single glance of the display.

Since the functions are not fully automated, tasks are not simplified enough. This also results in interactions with the system because the driver has to glance, look or even touch the display in order to use the new functions, thus removing the eyes off the road and engaging in an insecure action. Even though functions could become fully automated in upcoming years, drivers would still need to monitor and be aware why the system takes that specific action; this monitoring interface should also be designed properly.

From the results presented in the section 3.2 it is evident that car manufacturers do not follow a principled approach to the interface design, this results in lack of integrity of the functions and even duplicate information. Like it was shown before, 45% of the information is being provided constantly without reason. That means it will also generate mental workload or distraction to the driver if not presented properly. The driver has to divide his attention between driving tasks and continuous perception and processing of the information.

To summarize, the first gap is that physical functions have been increased and not integrated but added only. People would have trouble in detecting, discriminating, and interpreting the information unless it is provided properly. Sometimes it is too much, too complex or not given at the right time. If not properly integrated, the driver has to access different sources of information to handle the ad hoc situation.

4.2. Quality of Information

In former cars information that the driver received was limited, and thus it has to be processed by the driver just to make sense of what was going on and what action is need to be done. This made the driving task require a lot of experience and devoting the cognitive resources of the driver to the operation of the system; drivers need to be fully focused on driving only.

Information system designers in the former days faced a space issue due to that they had to use analog displays. Hence they solved this constraint by providing data that could be processed further by the driver for multiple purposes. For example, traditional speed meter provides current speed as raw data for judging speed violation and also for estimating arrival time for the destination. In each case, the driver needed to get another information such as speed limit of the road, remaining distance to the destination, among others.

What modern cars have as an advantage been the information that they provide can be designed and customized according to each driver's requirements and ultimately based on the system constraints. Nonetheless, it seems that manufacturers keep on showing information in the traditional way still in these days, in spite of having digital displays that could be customizable and showing the exact information in ad hoc situation. The driver still has to operate with independent information displays instead of an integrated information system.

As it was shown in the results, each driving task can be executed in three different levels of cognitive behavior: SBB, RBB and KBB. Among the new physical functions in the IVIS, only 25% of them support SBB which has the least mental workload. It means the driver is still needed to perform a complex level of information processing for the rest 75% of functions. Now it is obvious to say that the focus should be placed on reducing the amount of processing that the driver has to process further by himself. In order to let the driver being occupied on a basic cognitive level, it is important to make the system perform the information processing as much as possible. Then free cognitive resources of the driver could be employed to remain connected, entertained and also to act faster in the case that an unanticipated event takes place.

What would happen if applying EID approaches that all the sensors, functions and information be integrated and processed before being presented to the driver? For example, how relieved would the driver be if he wants to change lane and all he has to do is glance at the HUD for a “Go” signal. If the system provide proper decisions based on pre-processing of all the environment information and constraints, the driver could perform his task rely only on SBB. People have limited attention resources therefore information design has to be made simpler for the driver in order to make better interactions.

Therefore, the second gap is that information is not processed enough nor integrated in a functional manner by the IVIS before the presentation. If people do not receive properly processed information at the right time, decisions in this complex HMS could not be made in seconds or fraction of seconds which is critical to avoid accidents. Thus a proper abstraction and integration of information is needed to benefit the driver.

4.3 Distribution of Information

As was found from the results, information distribution throughout the three different types of displays has little to do with the timing or frequency of the information requirement by the driver. That means different characteristics of the 3 types of visual displays are not considered thoroughly in the design, and all the displays are packed with valuable but crowded and unorganized information.

The information regarding to a single physical function is given from different displays with scattered locations in many times, duplicate and definitely not integrated sometimes. Thus the driver’s first subtask is to figure out where the necessary information is and then access this information sequentially for integrating them to make a decision. This problem becomes worse if the driver uses more than one brand of car, because he has to learn as many information distributions as the numbers of cars he needs to operate since there is no standard option.

If somehow the car manufacturers could adapt a principled and standardized approach for distributing information based on the characteristics of each display used in the IVIS and the driver’s experience and knowledge level, he would only have to learn information array once in this ideal scenario. Thus it is clear that a new principled approach to interface design should be applied in order to make this new added powerful functions been taken advantage of, as easy as possible, by the driver.

5. Principled EID Approach for IVIS Design

Cars nowadays have incorporated functions to accomplish classic and modern driving tasks easily, but as was mentioned before they still lack a proper interaction with the driver. The purpose of applying an EID approach in this study is to suggest few principles to design IVIS to reduce driver’s mental workload. It could be done by primarily relying on providing properly abstracted information only when it is necessary and make use of information hierarchy to support all three levels of cognitive behavior at the same time.

This design should find a way to integrate the physical functions in a proper manner and abstract information before presenting it to the driver. In this way a new interface design could benefit the driver to get the power of these newly added physical functions while allowing this HMS to achieve its functional purpose simultaneously.

5.1 Principle #1: Consolidation and Parsimony

Interface designers nowadays need more physical spaces where to display information regarding to new functions added, and that's why the new displays like HUD and MFD had to appear. One disadvantage of using multiple visual displays is divided attention that the drivers have due to figure out where the information is and what information is of relevance to his tasks[25].

Since there is plenty of information requirements from the driver to interact with the modern physical functions, restricting the number of displays or sources of information is not the best option. Therefore, consolidation of the task related information is proposed as an alternative design approach. This means designers should minimize the number of displays to be accessed in turns by the diver to get all the necessary information for interacting with a single physical function. Consolidating all the related information into a single display would be the best if possible. In this way, effort of the driver to gather information can be reduced and the distraction can be minimized.

To avoid the distraction, information should be provided parsimoniously as well. The risk of the driver's attention being diverted away from the driving task can be caused by those functions trying to provide information at all the time, without taking into account the requirement of the driver under the situation. Ultimately this driver's attention diversion could be the cause of a vehicle crash[5]. Critical information should be given only when it is necessary so the driver can be confident that the given information at any time is valuable and attention redirection would be benefited to make safer driving. Therefore, constant display of information, which is neither urgent nor important, should be avoided in standard practice of EID approach to IVIS design.

5.2 Principle #2: Abstraction and Integration

Abstraction is a process of extracting relevant information only from the raw data or low level information and then coding it into comprehensible formats within a certain physical form. This abstraction or processing of information should take into account information requirement of the driver who is performing a specific task under given task environment. The driver's cognitive performance to understand the meaning and make a right decision based on the given information can be varied with two factors: the amount of his domain specific knowledge and the level of information abstraction.

Information requirement analysis with SRK framework can aid in the design of information displays by considering that the level of driver's experience and skills as the system constraints.

In this approach lower level information could be properly abstracted into high-level knowledge in advance by the system on the basis of the driver's requirement, and the driver will get to know by this assistance what reaction is needed to be done and why this happens if he wants to know. That means information shown to the driver must be designed in a way to support all levels of driver cognitive behavior according to his experience and knowledge level; allowing the driver to follow a series of instructions and operate solely on SBB or getting access to the properly abstracted information level prior to engaging directly in KBB.

The information should be processed and displayed following this SRK framework:

- SBB: Information that is to support SBB should tell the driver *what to do*, so the driver can perform the task without further information processing. This information needs to disappear after the message has been accepted.
- RBB: Information at RBB level of abstraction should tell the driver *why to do* those actions, or why certain actions are necessary. RBB is supported by logics to choose the right action.
- KBB: Information at KBB has the lowest abstraction level and should provide data and models to face complex and novel situations. The driver needs to understand these models with complex system constraints by his own thinking process in order to get the situation awareness and reach to a solution.

It becomes fundamental to integrate and coordinate all information regarding to the modern physical functions into a prioritization system so that individual display does not have to compete in order to get the driver's attention[5]. Each information given to the driver needs to be integrated as a total solution required at any particular moment. In this way, the driver can choose and react accordingly due only to the proper interaction with the display both in timing and format of the integrated information.

5.3 Principle #3: Utilization of Different Display Characteristics

Distribution of information throughout multiple displays should be designed by taking into consideration strength and weaknesses of the individual displays. The frequency of information display is also needed to be considered in this distribution to allow enough space for valuable information by removing unnecessary ones from perpetually cluttering driver's angle of view.

The three kinds of visual displays appeared in the recent IVIS could be used as follows:

- HUD: The information shown here must be urgent or utmost important. It should not be overcrowded since this could distract the driver from real world hazards. Information that is to support SBB at an urgent situation should be displayed here.
- HDD: This is for information that is not urgent but required in a regular basis by the driver. The driver could access this information when his attention resources are available. Information for supporting RBB would be better displayed here.
- MFD: This is for the information that is not urgent and needs more visual space due to its amount or complex hierarchical structures. Through this touchable display the driver could navigate multiple layers of information screens and control the functions. Data and models to support KBB would be better displayed here.

5.4 Principle #4: Standardization through Customization

To build more advanced and usable features into the IVIS, physical forms & formats of information in the IVIS should be customizable because the drivers have different information requirements due to individual differences in the levels of experience and knowledge, preference, and physical capability. For example, if the driver prefers to get the speed information as a digital number instead of an analog format, it should be changeable. Increased font size of displaying information would also benefit elderly drivers with impaired vision.

However, information distribution would better be standardized irrespective of car manufacturers since this standardized IVIS interface can ensure the driver an easier to learn and memory interacting environment no matter what car is operated.

It seems that these two principles, customization and standardization could not be compatible with each other but what if a couple of customizing options could be saved as a preset across different brands of cars? This would be possible if the car manufacturers allow third party developers to provide different options for customizing the IVIS interface that is compatible with different hardware setups. Cellphone apps work compatible with different brands and operating systems, showing this can also be done in the IVIS.

If this standardization through customization is adapted as proposed, not only driver's learning curve decrease even when driving different cars but the whole driving experience would become more enjoyable. The only thing for the manufacturers to do with this is checking out the compliance of the interfaces with the safety guidelines.

6. Conclusions

As their functions have become associated with more than transportation, recent automobiles are evolving into intelligent information systems. Though the purpose of any driving information system is to inform and ease the user while driving, too much information presented randomly on unorganized multiple displays may distract the driver's attention and cognitive process. Cognitive overload might cause significant deterioration of driving performance which could yield fatal consequences.

To settle this problem of cognitive overload while interacting with current IVIS to utilize physical functions of the car, this study proposes four principles for EID approach in the IVIS design.

The first principle, *Consolidation and Parsimony*, comes from the finding that there is too much information in the current IVIS because of the increasing number of new functions added on unintegrated way. This principle deals with how to reduce the quantity of information for managing the total amount of cognitive process to be performed by the driver.

The second one, *Abstraction and Integration*, is based on the fact that driving information should be given in a simple and comprehensible way so that the driver can be aware what and why to do as soon as possible. This principle deals with the way of enhancing the quality of information by the system so that the driver needs to spend his cognitive resource at lowest level.

The third one, *Utilization of different display characteristics*, is proposed because there are different features among the visual displays currently used in the IVIS (HUD, HDD, and MFD) in presenting information. This principle gives a strategy to find optimal information distribution subjected to the abstraction level of given information and the characteristics of the displays.

The last one, *Standardization through Customization*, is based on the finding that there is no standard approach for distributing information throughout the multiple displays among the car manufacturers. This principle suggests that it is possible for the driver to use customized user interface as he wants to appear in the IVIS across different brands of cars if the car manufacturers transfer their authority of developing the software user interface to the third party developers.

In this way of information design and distribution, people having different levels of driving experience would be easy to interact with new powerful functions of the car and stay in safe, comfortable driving environment without losing connectivity.

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