CHEMICAL ENGINEERING TRANSACTIONS

VOL. 107, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Bohong Wang, Petro Kapustenko

ISBN 979-12-81206-07-6; **ISSN** 2283-9216

DOI: 10.3303/CET23107070

Car Simulator Study for the Development of a Bring-Your-Own-Device (BYOD) Dashboard Concept

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In-Vehicle Information Systems (IVIS) have evolved with the integration of advanced technologies like touchscreens, enhancing vehicle functionality and infotainment features. However, the development of sustainable and user-centric dashboard interfaces embracing the Bring-Your-Own-Device (BYOD) concept remains limited. This research aims to explore the usability, advantages, and disadvantages of the BYOD concept within the context of IVIS. Specifically, it investigated the control of the onboard air conditioning system and selected Advanced Driver Assistance System (ADAS) functions. To accomplish this, a complex simulation environment using Unity, Blender, and C# was developed. Eye-tracking technology was utilized to record participants' gaze patterns and attention allocation during experimental tasks. Following the simulation, participants provided subjective usability assessments of the system through questionnaires. The integration of a mobile phone with a suitable user interface as part of the BYOD concept generally led to enhanced usability and reduced distraction. This study underscores the potential benefits of integrating the BYOD concept into IVIS, emphasizing improved usability, sustainability, and user-friendliness. These findings hold significance for advancing the design of user-centric, sustainable interfaces in automotive technology.

1. Introduction

Before fully automated road vehicles become commonplace, it's essential to thoroughly investigate the existing Driver-Vehicle communication systems and technologies while also exploring the development of more sustainable alternatives. This research primarily aimed to examine the visual demands and distractions associated with various IVIS, including a tailored BYOD User Interface (UI) concept. The shift towards using personal smart devices instead of integrated on-board touchscreens not only aligns with cost-saving strategies but also presents a promising area for further sustainability studies.

Driver distraction is caused by simple non-driving-related tasks (NDRTs), and the severity of this distraction is determined by the nature and ergonomics of the UI. The occlusion technique is commonly employed in research to evaluate In-Vehicle Information System (IVIS) displays. These studies aim to validate outcomes using a low-fidelity simulator and establish compliance criteria for the National Highway Traffic Safety Administration's Driver Distraction Guidelines (NHTSA, 2014). An alternative approach to detecting distractions involves the use of eye-tracking systems, which yield more pertinent insights into glancing behaviour. Research indicates that different NDRTs exert varying effects on driving behaviour, with auditory and audiovisual stimuli prompting quicker responses than visual cues (Liu, 2001). A detailed usability assessment of a touch button interface was performed, evaluating factors such as button size, colour, shape, and design combinations (Jung et al., 2021). Analysis of gaze data and off-the-road glances revealed variations in driving and visual performance (Zhang et al., 2023).

1.1 Human Machine Interface in vehicles

Human Machine Interfaces (HMIs) were developed to enable effective vehicle-driver interaction, while in other cases, studies focused on efficient Graphical User Interfaces (GUI) for efficient process monitoring (Rahim and Ahmad, 2017). HMIs in vehicles (both road and rail) are made up of output and input channels. The output channels give the driver information on the system status (through displays and audio signals, for example) or energy consumption and energy-saving capabilities via an advanced monitoring and assisting system for train

Paper Received: 16 April 2023; Revised: 16 July 2023; Accepted: 22 October 2023
Please cite this article as: Nagy V., Kovács G., Földesi P., Sándor Á.P., 2023, Car Simulator Study for the Development of a Bring-Your-Own-Device (BYOD) Dashboard Concept, Chemical Engineering Transactions, 107, 415-420 DOI:10.3303/CET23107070

operators (Fischer and Szürke, 2023). The input channels detect the driver's intent to input data (through buttons, steering wheel, or pedals) (Bengler et al., 2020). The most common HMI input interfaces in production vehicles are dedicated tactile switches paired with menu-based on-screen projected control panels. Speech recognition, handwriting recognition, and gesture recognition are being implemented in automotive technologies for NDRTs (Pickering et al., 2007). The increasing sophistication of IVIS was caused by the increasing degree of instrumentation and the ambition of car makers to provide modern technologies to luxury vehicles (Birrell and Young, 2011). The multi-coloured touchscreens, which have swiftly gained popularity, are predicted to improve usability and performance (Pitts et al., 2014). Touchscreen efficiency is also affected by screen size and other GUI design elements such as button size, button spacing, button shape, button colour, and visual or haptic feedback. IVIS is primarily responsible for basic vehicle settings such as entertainment (e.g., music, phone calls), integration with nomadic devices (e.g., cell phones), advanced navigation, and other comfort features (e.g., climate control, seat heating). Our study evaluates the usability of essential comfort and safety features as NDRTs.

1.2 Driving Tasks and Non-Driving Tasks

Driving a road car is more complicated than just pressing the pedals and rotating a steering wheel. With respect to driving, three task categories can be characterised as follows (Pfleging and Schmidt, 2015):

- Primary Driving Task: Manoeuvring the vehicle, detecting hazards (e.g., managing speed, assessing distance to other road users), and hierarchically cascading tasks (navigation, guidance, stabilisation).
- Secondary Driving Task: Safety-related functions (e.g., turn signal, windshield wipers).
- Tertiary Driving Task (NDRT): All entertainment, comfort, and information system features.

1.3 Driver distraction

Driver distraction is defined in the literature as "the diversion of attention away from activities critical for safe driving toward a competing activity" (Regan et al., 2008). Driver inattention can be estimated using eye tracking and appropriate algorithms, but drivers still have visual spare capacity or off-target looks (Kircher and Ahlstrom, 2017). The National Highway Traffic Safety Administration (NHTSA) in the United States categorises distractions into four types: visual, auditory, biomechanical (manual or physical), and cognitive. In our study, visual distraction (Area of Interest detection with eye-tracker) and driver performance measurements (vehicle data collection) were in focus.

1.4 Bring-Your-Own-Device in vehicles

Bring-your-own-device (BYOD) refers to the act of bringing your own gadget or equipment to an organisation or institution. It is a rapidly expanding concept, particularly in information technology (IT) consortia (Blay, 2022) and educational institutions (Afreen, 2014). BYOD is simply the process of letting employees or students connect their own devices to the organisational or institutional facilities and network.

The automotive applicability of BYOD in our study means the (re)usability of mobile devices (e.g., cell phones) as an IVIS interface, reducing the number of displays that need to be installed in the vehicle (Buckley and Mesa, 1999). Our approach to mobile device uses in vehicles and the BYOD idea is based on personalisation, universality, and multifunctionality. These, along with cost efficiency, result in a higher level of system sustainability.

2. Methods

The methodology of examination of the differences in on-board user interfaces is based on a previous naturalistic driving study of Nagy et al. (2023). This pilot test was carried out on 18 participants (N = 18) as volunteers (they were not compensated). The participants had different lengths of driving experience. The three female and fifteen male participants were 24 to 50 y old (Mean 37.7 y, Standard Deviation 8.1). In the simulation driving study, the model of a closed track (High-Speed Handling Course) at ZalaZONE Test Center, Hungary) was used.

2.1 Apparatus

In this research study, a comprehensive apparatus was utilised to investigate the usability and advantages of the BYOD concept in the context of automotive user interfaces. The primary components of the apparatus include a purpose-built car simulator, an advanced eye-tracking system, and data recording and analysis software.

Pupil Labs Core, a head-mounted eye-tracker device, was used for gaze detection. The binocular glasses of Pupil Labs were chosen because they are the most accurate among similar devices (Macinnes et al., 2018). The glasses were equipped with 2 infrared (IR) eye cameras and one RGB world-view camera with a wide-

angle lens. The mobile eye-tracking system contains recording and analytics software with GUI to visualise video and gaze data (Kassner et al., 2014). To ensure accurate calibration and reliable data collection, after the physical installation of the wearable device on the head of the participants, the eye cameras were precisely adjusted, and a semi-automated calibration process was performed for each participant before the driving test. Additionally, ID-tag markers were strategically placed around the centre console of the dashboard and the driver's view field (LCD screen imitating the windscreen) for post-processing and data validation.
The car simulator was designed using the Unity game engine and was programmed in C# to accurately replicate the behaviour of an electric car, which allowed participants to engage in a realistic driving experience. The car's control system was integrated with the Logitech GSDK. The simulator's control system encompassed crucial input parameters and featured informative on-screen elements (imitating Head-Up-Display technology). To introduce a level of dynamism and challenge in the driving tasks, the simulator implemented various features: 1. Speed-dependent steering sensitivity; 2. Drift effects in high-speed turns; 3. A vibration area trigger. To collect valuable data for analysis, the simulator was equipped with a data recording system.
In this study, the following two types of interfaces were analysed:

- Android Automotive Operating System-based dummy GUI (from Polestar 2 mass production car) running on a tablet with an 11.6-inch size IPS touch screen (Tablet)
- Custom HTML-based GUI running on a phone with a 6.55-inch size OLED touch screen (Phone)

Our experimental system combined timestamped data from a car simulator and eye-tracking device to effectively detect areas of interest (AOI: Tablet or Phone). It enabled in-depth analysis of crucial metrics such as eyes-off-the-road time periods, vehicle movement patterns, and data from vehicle control devices.

3. Procedure

The concept of the test was to measure the differences in visual distraction driving performance while performing short NDRTs using two different touch interfaces. The participants were verbally instructed before the procedure and shown how to use the actual interfaces of the dummy dashboard before the test. The participants were driving one round on the track, starting at the 450 m long, three-lane straight section, and when they returned to this straight section, they were instructed to do the tasks (Figure 1). The instructors always gave identical instructions to each participant, and all test circumstances were identical for all participants.

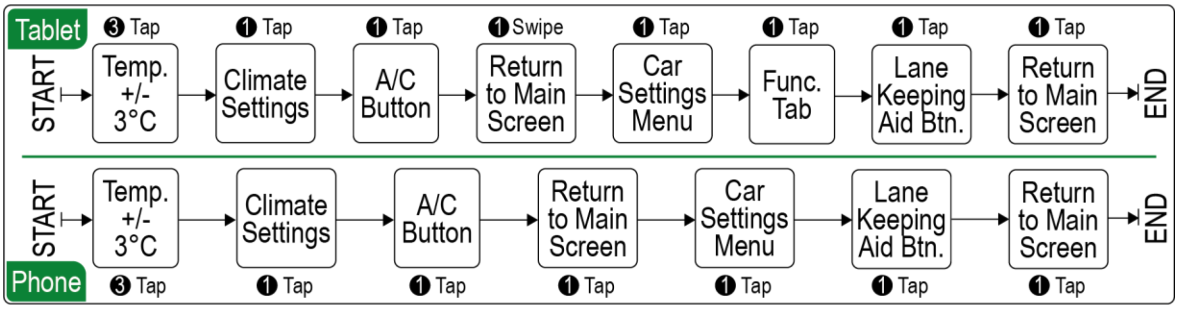

Figure 1: Flowchart showing tasks done by the participants on Tablet and Phone

The task was to set the internal temperature of the vehicle by using the climate system controllers positioned on the bottom of each touch screen. Specifically, participants had to increase or decrease the temperature by 3 Celsius in three steps. The next step was to enable A/C by entering the Climate Control Settings (CCS) menu/screen and tapping the appropriate button. After exiting CCS, Lane Keeping Aid (LKA) had to be enabled by entering the Car Settings menu/screen. The two GUI had differences in the structure of this screen as the Tablet version had more tabs and had to switch to the “Functions” tab. This resulted in 1 more tap for the same function compared to Phone GUI.

4. Results

4.1 Eyes-off-the-road

The duration of visual distraction can be detected by the eye-tracking data with AOI tracking; the outcome of this analysis is the Total Eyes-off-the-road Time (TEORT). TEORT values were summarised from the gaze data of all participants (Table 1.).

Table 1: TEORT and statistical values

	Mean [s]	Max [s]	Min [s]	Standard deviation [s]	Mean deviation [s]	CI 95% [s]
Tablet	11.48	29.16	3.47	5.71	3.88	2.80
Phone	10.00	16.66	4.10	4.32	3.07	2.11

The mean TEAORT values, measured in seconds, show a 12.9 % reduction when using the phone. Simple main effects analysis showed that interface design did not have a statistically significant effect on TEORT (F(1, 34) = 0.9¸p = 0.34).

4.2 Steering intensity

Steering Intensity (SI) as lateral corrections while performing IVIS tasks show the level of distraction. SI refers to how much a driver has to adjust the steering wheel (turning it left or right) while they are interacting with the IVIS. The steering intensity is detected by monitoring the steering angle and collecting maximum amplitudes while the interfaces are used. The minimum and maximum absolute values of means were used to calculate SI (Table 2.).

Table 2: SI and statistical values

	Mean [deg]	Max [deg]	Min [deg]	Standard deviation [deg]	Mean deviation [deg]	CI 95 % [deg]
Tablet	34.30	194.08	3.42	42.25	22.04	20.70
Phone	24.71	67.26	5.41	16.78	13.80	8.22

The average SI values, measured in degrees, exhibit a 28 % decrease when using the phone. Simple main effects analysis showed that interface design did not have a statistically significant effect on SI (F(1, 34) = 0.8¸p = 0.37).

4.3 NASA-TLX

Subjective measures of mental load and cognitive distraction are required to validate the results of eye-tracking glasses. NASA-TLX survey was chosen because it reflects the cognitive component of the workload ease to use for non-professional participants, and it is the most frequently used questionnaire in scientific publications (von Janczewski et al., 2022). The test contains six subscales: Mental Demand, Physical Demand, Temporal Demand, Own Performance, Effort, and Frustration Level (Hart and Staveland, 1988). Participants scored on a 1–7 scale, which was converted into a value from 0–100, as shown in Table 3.

Table 3: NASA-TLX scores and statistical values

	Mean	Max	Min	Standard deviation	Mean deviation	CI 95 %
Tablet	57.41	83.33	28.57	15.69	12.43	7.69
Phone	41.27	73.81	16.67	16.02	12.96	7.85

Simple main effects analysis showed that interface design did have a statistically significant effect on mental workload according to NASA-TLX (F(1, 34) = 9.32¸ p = 0.004), and the Phone was 28 % less distracting according to the participants.

4.4 Data representation

For a better representation of the results, Type-2 fuzzy sets were introduced, which are capable of handling multiple uncertainties due to the conditions of the test carried out, the relatively small values of parameters, and the relatively high standard deviations (Li et al., 2023). The fuzzy set “Higher Distraction Level” (HDL) was constructed as follows:
Let N be the number of test participants. Let R_i $(i = 1 \dots N)$ be the observed comparison, that is ,$R_i = 1$ if the i^{th}participants parameter (potential distracting element) is higher, and $R_i = 1$ when the value is smaller. The membership function is Type-2 fuzzy:

$$\mu\,(HDL) = \alpha \frac{\sum_{i=1}^{N} R_i | R_i = 1}{N} \tag{1}$$

and

$$\alpha = \begin{cases} 1 \quad if \quad \overline{P}_T + 2\sigma_T \geq \overline{P}_P + 2\sigma_P \\ \quad and \\ 1 - \dfrac{\overline{P}_P + 2\sigma_P - (\overline{P}_T + 2\sigma_T)}{\overline{P}_P} \quad otherwise \end{cases} \tag{2}$$

where $\overline{P}_T$ and $\overline{P}_P$ are mean values of observed results of Tablet and Phone. σ_T and σ_P are the SD of the above statistics. Table 4. shows that $\overline{P}_P$ (Phone) parameters are more favorable but the larger SD (σ_P) reminds us of the uncertainty of the comparison. HDL is discoverable in more cases, still the reliability of data is low for conventional statistical analysis.

Table 4: Type-2 fuzzy analysis for TEORT and SI

	TEORT			SI		
	α	R	μ	α	R	μ
Tablet vs Phone	0.63	10	0.28	0.77	11	0.30

5. Discussion

Regarding the novelty of our study on implementing the Bring Your Own Device (BYOD) concept in cars, noteworthy observations has been made:

- The suitability of the graphical user interface (GUI) on compact devices has been demonstrated.
- The choice of screen technology, such as comparing IPS and OLED, has been found to significantly enhance readability and convenience.
- Utilizing a smaller screen size has been linked to improved focus and task performance.
- The consolidation of multiple functions onto a single screen in the context of BYOD exhibits heightened sustainability by reducing the number of devices required.
- The application of the BYOD concept holds promise in various scenarios: budget cars, car-sharing fleets, customisable user interfaces, and offering enhanced convenience to individuals with disabilities.

In conclusion, our study highlights the potential advantages and innovative aspects of incorporating the BYOD concept into automotive applications. When coupled with the application of cost-effective driving strategies and models, this concept has the capacity to augment the overall efficiency of both vehicle manufacturing and utilisation, aligning with comprehensive sustainability objectives (Pusztai et al., 2021).

6. Conclusions

The combination of driving simulation, gaze tracking, and comprehensive data collection allowed the examination of participants' driving behaviour and visual attention. Our small touch screen BYOD concept with an optimised GUI resulted in a significant 28 % reduction in user distraction, according to the NASA-TLX test results. Users experienced 12.9 % shorter periods with their eyes off the road when interacting with our system, and the need for steering corrections was reduced by 28 % when using our BYOD concept. These facilitate the integration of similar technologies for the automotive industry in the future, promoting higher sustainability and more economical manufacturing.

Acknowledgements

The authors wish to acknowledge the support received from the Vehicle Industry Research Centre and Széchenyi István University, Győr. The research presented in this paper was supported by the ELKH-SZE Research Group for Cognitive Mapping of Decision Support Systems. The research was carried out as a part of the Cooperative Doctoral Program supported by the National Research, Development and Innovation Office and Ministry of Culture and Innovation.

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