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► To cite this version:

Mathilde Francois, François Osiurak, Alexandra Fort, Philippe Crave, Jordan Navarro. Usability and acceptance of truck dashboards designed by drivers: two participatory design approaches compared to a user-centered design. *International Journal of Industrial Ergonomics*, 2021, 81, 10.1016/j.ergon.2020.103073 . hal-03186322

HAL Id: hal-03186322

<https://hal.science/hal-03186322v1>

Submitted on 15 Dec 2022

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aUsability and acceptance of truck dashboards designed by drivers: two participatory design approaches compared to a user-centered design

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Running head

Participatory versus Used-Centered Design

Abstract

Previous literature reported that Participatory Design (PD) results in satisfying products and presents other subjective benefits. PD implies an active involvement of users during all steps of the design process, including during concepts specification (contrary to user-centered design, UCD). This study compared the usability and acceptance of truck dashboards resulting either from a PD or from a UCD design processes. Moreover, design concepts from two PD approaches were compared: a collective versus an individual design session. Results showed that concepts resulting from user-centered design and individual design sessions were perceived as more usable and accepted than the concept resulting from the participatory workshop. These findings question PD benefits and encourage to further explore the different PD approaches in the industrial development of truck dashboards.

Keywords

Participatory design; participatory workshop; personalization; truck interfaces; automotive dashboards

1. Introduction

On truck dashboards, human-machine interfaces (HMI) mediate all interactions between the driver and the truck. The driver can communicate with the truck through controls, stalks, remotes, etc. Inversely, communication from the vehicle to the driver is mainly provided through the instrument cluster. The instrument cluster, often located behind the steering wheel, provides information such as vehicle state (e.g. truck speed, engine speed, gauges), function feedbacks (e.g. turn signal indicator light), or mechanical issues (e.g. warning lights, alerts). Center stack screens are also widely used and are mainly dedicated to secondary information and entertainment. The instrument cluster is particularly important in its design because it brings together primary driving information which is thus critical for road safety. When designing a new instrument cluster, some human factor considerations have to be taken into account to face today's challenges.

1.1. Truck dashboard design: usability and acceptance challenges

Designing an instrument cluster consists in defining which information to present to the driver, how and when to display it and to specify a logic of interaction. The major consideration when designing truck instrument cluster is that the interface will mainly be used while driving (Marcus, 2004). In this dual task situation, every interaction with the cluster can create interference, either positive or negative, with the primary driving task. Distraction caused by the interaction is therefore an essential criterion of assessment of an interface and distinguishes automotive HMI from other user interfaces (Harvey, Stanton, Pickering, McDonald, & Zheng, 2011). Objective measures linked to usage should be minimized, such as time required performing a task, amount of cognitive resources engaged, or eyes off road duration while interacting with the cluster (Harvey et al., 2011). Besides objective criteria, interpretive and subjective aspects have to be considered by designers because they play a key role in driver comfort and increase system willingness to use. These subjective aspects can be grouped under two criteria: perceived usability and acceptance (François, Osiurak,

Fort, Crave, & Navarro, 2017a). Nielsen (2012) defined usability as 'a quality attribute that assesses how easy user interfaces are to use'. He broke down usability into five criteria: an interface should be easy to learn (i.e. learnability); it should allow the user to perform a task without requiring unnecessary resources (i.e. efficiency); it should be easy to remember how to use it after a non-use period (i.e. memorability); it should be used without causing mistakes (i.e. errors); and using the interface should be pleasant (i.e. satisfaction). This notion of usability is very close to the idea of acceptance. Acceptance is defined as 'the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving' (Adell, 2010). Davis, Bagozzi and Warshaw (1989) proposed that acceptance (i.e. intention to use) is dependent on two factors: perceived usefulness and perceived ease of use. For example, a driver could neglect a system that they would not need, or if they would feel too much difficulty in using it. Thus, usability (i.e. ease of use) would be a predictor of user acceptance of a system (Venkatesh & Davis, 2000). The two notions are based on user perceptions, beliefs, attitudes and intentions (Davis et al., 1989).

Usability and acceptance are important criteria in the design process of a truck instrument cluster. From a marketing point of view, the difference between vehicles from different brands is moving further away from technical aspects. The comfort of the driver and his satisfaction in use became determinant (Marcus, 2004). Different factors are challenging usability and acceptance during the design of trucks interfaces. First, information amount and complexity have increased (Gkouskos, Normark, & Lundgren, 2014). Twenty years ago, the main technical information available was basic vehicle information (e.g. speed). Today, some complex information can be displayed to the driver, such as the following distance set for the adaptive cruise control or the remaining driving time with regard to the legislation. Second, for the same truck instrument cluster, there is a high diversity of contexts of use. There is a broad range of truck drivers in terms of experience level, motivation, age, expertise, emotional status, time pressure, relation to technology, etc. Moreover, regarding environmental factors, there is a wide range of road and traffic environments (e.g. city,

construction areas, highway) and different tasks and usages with different needs in terms of information (e.g. fire trucks, tankers, moving trucks). For example, the same instrument cluster can be used by a fireman travelling at high speed, or by a novice distribution driver delivering in a city center with many pedestrians around, or by an old driver reluctant to new technologies driving a car-carrying truck on a highway. The challenges in terms of usability and acceptance are therefore unique compared to clusters found in cars. Finally, instrument clusters in vehicles become screens, bringing with them dynamism and flexibility, but also many possibilities of interface layouts that cannot all be tested in classical usability tests.

1.2. From a design with users to a design by user

Human-centered design puts the user into the center of design, instead of the extent of technological features and technical constraints imposed by the technology. During a human-centered design process, three stages follow each other in an iterative process: analyses (understand and specify the context of use and user requirements), concepts design (produce design solutions to meet user requirements) and concepts assessment (evaluate the designs against requirements) (International Organization for Standardization [ISO] 9241-210, 2010). The ISO 9241-210 guideline (2010) recommends an active involvement of users during the design process. Nevertheless, users can be involved at different times and in many ways. Different levels of user involvement in design processes were defined (Damodaran, 1996; Eason, 1995). First, a design *for* users – informative involvement – consists in involving users as a source of information. Designers collect information during the analyses phase, using techniques such as surveys, interviews, observations, activity analysis, focus group, etc. (e.g. Huang, Yang, & Lv, 2018). Second, a design *with* users – consultative involvement – considers users as objects of observation and commentators. Users are involved during the analyses phase, but also during the assessment phase. They evaluate one or several products defined by designers, to identify usability issues and collect data or user performance and satisfaction (usability test, e.g. Camargo, Wendling, & Bonjour, 2014). Finally, in a design *by* users – participative involvement –, users are actively involved

all along the process. That is to say during analyses and assessment phases, but also during the concept design phase. User involvement in real case studies is not as clear and delimited. Damodaran (1996) stressed that forms of involvement can be characterized on a continuum from informative to participative. Even if boundaries are not clear, two major human-centered approaches can be differentiated (Bekker & Long 2000; Carroll, 1996; Kujala, 2003; Sanders, 2002; Spinuzzi, 2005):

- User-centered design (UCD) would imply a consultative involvement (users are involved during analyses and assessment phase, concepts are designed by experts)
- Participatory design (PD) would imply a participative involvement (users are involved during analyses and assessment phase, but also in the concept design phase)

Today, instrument clusters for trucks are mainly defined using user-centered design processes. HMI designers define concepts considering various aspects and requirements such as industrial engineering, cognitive ergonomics, technical possibilities, project-lead times, brand image, etc. Moreover, involving drivers during the phases of analyses and assessment allows considering interface usability and users needs and expectations (e.g. Tang, Sun, & Cao, 2020). However, user-centered design focuses principally on how users react to a concept and fails to capture what they could bring to the concept design. Carroll and Rosson (2007) stated that a shift from user-centered design towards participatory design could bring two types of benefits. First, a 'moral' benefit would rely on the fact that users would have a right to be involved in decision-making. Second, a 'pragmatic' benefit would be due to the fact that users' experience and knowledge can offer insights and increase the chances of a successful design outcome. Sanders (2002) pointed up that what we can learn from what users say/think and do/use is not enough. Explicit knowledge and observed experience do not give access to what users feel and implicitly know (i.e. tacit knowledge; Spinuzzi, 2005). Kujala (2003) stated that, in a consultative involvement, users can easily say what is wrong or difficult to use and could silence what is essential for them because they are too familiar using it. One way to access these aspects would be to let users make a

concept. In this situation (and with appropriate 'make tools'), skills and past experiences would be direct resources in the design process (Sanders, 2002). Drivers' implicit knowledge and experiences used as resources in the concept design stage could thus lead to better efficiency, learnability, memorability, a lower error rate and therefore increased HMI usability (François et al., 2017a). Prototyping concepts would also give an access to different levels of driver's needs (i.e. explicit, tacit and latent) (Sanders, 2002). This would promote the usefulness of the concepts generated. By improving the ease of use, as well as the usefulness of the concepts, a participative design would have a beneficial effect on the acceptance of the outcomes (Chowdhury et al., 2014). Although there is a lack of systematic and rigorous assessment of participatory design outcomes (François et al., 2017a), previous studies in other fields reported subjective benefits directly linked to usability and acceptance: self-confidence (Clement & Van den Besselaar, 1993); personal relevance (Kujala, 2003); satisfaction (Abelein, Sharp, & Paech, 2013); and system usage (Kujala, 2003). Moreover, in the automotive field, Normark and Gustafsson (2014) reported a high acceptance and usability of in-vehicle systems customized by car drivers.

1.3. A design by drivers: different participatory design methods

As defined in the preceding paragraph, participatory design would cover all approaches involving users during the three phases of the design process, including concept design. However, there is variety of ways to lead design sessions with a participative involvement (Sanders, Brandt, & Binder, 2010). Furthermore, roles of designers during design sessions can vary, on a continuum from co-designers to facilitators (Sanders & Stappers, 2008; also called 'emancipators' by Bekker & Long, 2000). In this article, we focused on an advanced form of participatory design, the 'design by users', in which users have a role of designers (and 'expert of their experiences') and designers become facilitators (Sleeswijk Visser, Stappers, & Van der Lugt, 2005). During the session, designers have the responsibility for framing, leading, guiding and 'providing scaffolds as well as clean slates' to encourage user to design (Sanders & Stappers, 2008). In order for them to take on this role, one key point is

to give to users the appropriate tools for expressing themselves (Sanders, 2002). Indeed, users having no design degree and professional tools can be difficult to master in a limited time. Moreover, without an appropriate visual 'make-tool', the potential difference of language and cultural background between designers and users can lead to misunderstanding and communication difficulties (Sanders, 2002). This has long been a limit to participatory design. Bruno and Muzzupappa (2010) suggested that users prefer discussing around existing products and expensive prototypes are often realized too late in the design process. Nevertheless, advances in technologies addressed this point. Touchscreens, 3D or virtual reality (Bruno & Muzzupappa, 2010; Österman, Berlin, & Bligård, 2016) are tools that are easy to use and allow users to have the full designer role during participatory design sessions.

Kujala (2003) cited two typical participatory design methods: workshops and prototyping. Sanders et al. (2010) suggested that 'the ideal situation' for a participatory design session is to lead a workshop containing three types of activities: telling, making and enacting. For our design case, the 'telling activity' would correspond to narrative tools that address drivers' experiences, needs and feelings. The 'making activity' would relate to the design session using an appropriate tool. The 'enacting activity' would imply a driving situation to contextualize the created concept. Sanders et al. (2010) also reported that workshops can be conducted either with users in groups or individually. Participatory workshops with users in group is widely used (e.g. Cinto, Ávila, & De Souza, 2015; Dickinson, Lochrie, & Egglestone, 2015; Khaled & Vasalou, 2014; Lamas, Burnett, Cobb, & Harvey, 2015; Lindsay, Jackson, Schofield, & Olivier, 2012; Naweed, Ward, Gourlay, & Dawson, 2018; Palaigeorgiou, Triantafyllakos, & Tsinakos, 2011; Seim & Broberg, 2010). The number of users involved depends on the design case: small groups allow providing intensive support, while larger groups allow collecting a wider range of inputs. The advantage of workshops in groups would rely on consensus building and collective intelligence (Sanoff, 2007). This would reduce the bias exposed by Madrigal and McClain (2011), suggesting that users would design for

their personal wants and needs and not in a common interest. Besides participatory workshops with several users, individual design sessions could present other benefits. Even if it is more time-consuming than group sessions, Sleeswijk Visser et al. (2005) reported that individual sessions bring out detailed information and a better access to individual experiences. Moreover, individual design sessions are in line with the trend of personalizable products which is becoming increasingly widespread. Fan and Poole (2006) pointed out that during personalization, design outcomes are more influenced by particular individual needs rather than by group norms and stereotypes. Mugge, Schoormans and Schifferstein (2009) also specified that personalization have the advantage of including actual users in the design instead a subset of users that would represent them. To compare individual and collective participatory design outcomes is essential for practitioners. Indeed, most studies reporting benefits for participatory design are based on collective workshops (e.g. Cinto, Ávila, & De Souza, 2015). However, the personalization perspectives involve an evaluation of the concepts resulting from an individual participatory design. Moreover, these two methods involve very different resources (i.e. cost, time) and it seemed interesting to evaluate the differences in terms of outcomes. Therefore, as they are very different, Group Participatory and Individual Participatory are addressed in this article as separate design methods.

1.4. Objectives and hypotheses

The objective of this study was to assess and compare three instrument cluster concepts generated with three different methodologies. The three concepts corresponded to different levels of driver involvement: user-centered design (UCD), participatory design workshop (PDWS) and Individual Participatory Design (PDInd). The three concepts were assessed and compared in terms of usability and acceptance using questionnaires.

Based on the literature, participatory design would increase usability and acceptance thanks to a direct access to drivers' need and tacit knowledge. However, there is a lack of rigorous comparative studies of the outcomes from different levels of user involvement (Bratteteig &

Wagner, 2016; François et al., 2017a). Moreover, subjective benefits are often addressed globally to participatory design whatever the approach implemented, although there are significant differences between them. This study is particularly relevant today with the rise of the implicit assumption that the more data feedback we have from the users, the more the design will, in result, have encompassing qualities. Design thinking processes and co-creation workshop are increasingly implemented by User Experience designers and researchers, often without formal arguments for the use of one method rather than another (Bjögvinsson, Ehn, & Hillgren, 2012).

The following research questions are raised:

- RQ1: Do instrument cluster concepts resulting from user-centered design differ from those resulting from participatory design in terms of usability and acceptance?
- RQ2: Is there a usability and acceptance gap between outcomes from two participatory design methods?

To investigate these questions, the first step consisted in the generation of the three concepts. During the second step, the three concepts were compared in a simulator test with questionnaires measuring acceptance and usability.

2. Step 1: Concept generation

Three concepts of instrument clusters were generated according to three design methods:

- User-centered design (UCD): two professional HMI designers defined a concept
- Participatory workshop (PDWS): four drivers were invited to a one-day workshop to define together a concept
- Individual participatory design (PDInd): 27 drivers participated on three hours individual sessions and each driver defined his own concept

The equipment, instructions and scope were the same for the three methods.

2.1. Equipment

Concept generation was made using a homemade software on a touchscreen (i.e. an app defined and developed by the authors). The touchscreen was installed on a fixed-base medium-fidelity driving simulator to allow iterative driving during concepts design (**Figure 1**). The software, as a 'make tool', was developed especially for this study to define all concepts with the same equipment. It was developed with Adobe Flash (now called Adobe Animate) and displayed on a 22 inches touchscreen. A 'function panel' was presented on the left of the screen (list of functions available: e.g. speed) and the stage was presented on the right with an empty instrument cluster (**Figure 1**). When a function was selected on the 'function panel' (e.g. speed), a 'widget panel' appeared with all the available representations for this function (e.g. digital speed, circular analogue speedometer, linear horizontal analogue speedometer). The user could then select the widget they wanted to display. The selected widget appeared on the stage and could be moved, rescaled, or deleted. Each widget proposed in the software was created based on a preliminary exploration of existing representations in today's trucks on the European market and on the available representations in cars' full dynamic clusters. Seventeen functions categories were presented, with a total of 186 different available widgets. The background, size and shape of the stage were imposed (see **Figure 1**). It consisted in a kind of oval form including in the center an eight inches surface and warning lights around (white and black). The goal was to simulate an oval hardware containing warning lights and a screen instrument cluster of eight inches. Users were allowed to arrange widgets in the eight inches screen surface only.

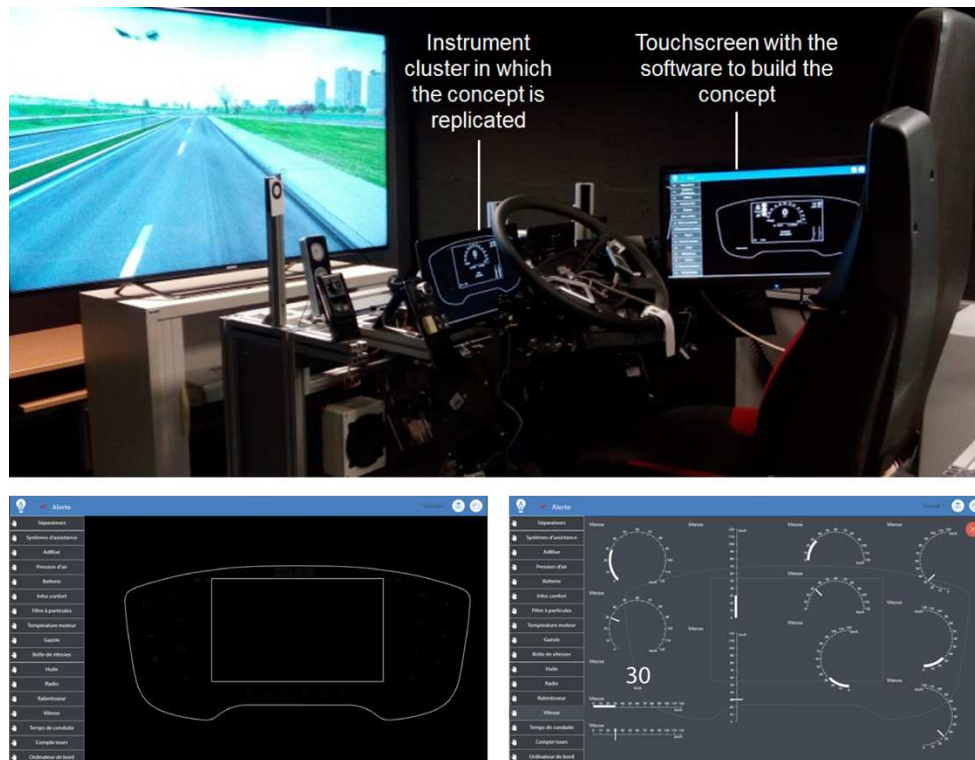


Figure 1. Equipment setup. On the driving simulator, users could design their interface on the touchscreen to the right. The dashboard was reported instantly and functionally behind the steering wheel (connected to the dynamic model of the truck in the simulator). The software on the touchscreen is shown on the bottom images, the user chooses a function in the function panel on the left and it opens a widget panel with all the representations available. Thus, the user could choose a widget that was displayed on the stage. The user could then change its size and location.

While building the instrument cluster on the touchscreen, the content was instantaneously displayed to scale on a screen behind the steering wheel. This 15.4 inches screen was located in place of a classic instrument cluster (height: 332mm, width: 207mm, resolution: 1280x800). While driving on the simulator, widgets were functional and interactive (e.g. driven speed update, level of resting fuel updated, radio station listened).

2.2. User-centered design (UCD): a concept defined by HMI experts

2.2.1. Participants

A concept was first designed by HMI experts. This concept was made first to avoid potential influence from drivers' concepts. Two professional HMI experts participated: a man and a woman; respectively 40 and 42 years old. They both worked more than ten years at Renault Trucks, defining trucks HMI. In company projects, they both have responsibility to define HMI

content, characteristics, layout, strategy, etc. Both experts graduated as engineers and received afterwards training in cognitive ergonomics and human factors. They led several user-centered activities in the past to increase their knowledge on truck drivers' activities and needs (e.g. surveys, activity analyses and focus groups). The user requirements they provide are based on this knowledge of the context of use.

2.2.2. Procedure

The two experts were first invited for one design session of four hours. A list of mandatory functions to display was made available to them (among the 186 widgets available divided into 17 functions): speed, gearbox information (mode and lever position), retarder, mode and target speed of the driver assistance systems. Among information to be chosen by participants, only the speedometer is regulated and mandatory to display. The other functions in the mandatory list are linked to commands that do not allow the activation feedback to be displayed (e.g. the gearbox lever is unstable). After some iteration between designers, three different concepts were defined. As it is required for user-centered design methods, a feedback was asked from drivers to evaluate these three concepts. The objective was to collect a feedback on the concepts, detect most important interaction issues and redesign a final concept based on these data. Nine Renault Trucks test-drivers interacted with the three concepts, in a counterbalanced order. They could dynamically experience each concept while driving on the simulator, on a straight road and without specific instruction on the tasks to complete. Their spontaneous remarks, their order of preference and satisfaction scores (between zero and ten) for each concept were collected. One of three concepts was significantly preferred by drivers. Based on the remarks, redesign was made on the basis of the preferred concept with some adaptations (e.g. bigger tachometer, retarder level presented with the icon, date-hour-external temperature grouped).

2.2.3. Outcomes and concept description

After redesign, the UCD concept contained 23 widgets (including four graphical separators; **Figure 2**). The size of 16 widgets was modified by designers (five of them were made bigger

and eleven smaller). Moreover, research has been carried out on the impact of the negative space in web interfaces and has shown an effect on usability and user acceptance (Liu & Ko, 2017). Kim, Dey, Lee and Forlizzi (2011) recommended to use 'ample white space' to improve usability (white space referring here to the negative space). To give an idea of the visual density of the concept, the percentage of white in the UCD concept was 10.60%.



Figure 2. Concept resulting from the user-centered design process (UCD concept).

The concept was generated by using human factors guidelines. Some examples are listed below:

- Information was grouped by function (e.g. driving and break times), or by groups that are semantically related and meaningful to the user (e.g. retarder and gearbox information). Seven groups were formed: speed mode information (cruise control on the top left), speed and tachometer (center), retarder and gearbox (top right), vehicle gauges (right), radio information (bottom right), comfort information (hour, date, external temperature on the bottom) and driving times information (bottom left). The principle of functional grouping was followed (SAE J1138, 2009; ISO 9241-12, 1998) and the number of 'chunks' did not overpass seven, as required to facilitate memorization (ISO 9241-12, 1998).
- Representation chosen supported drivers' mental model of reality, as recommended by Ross et al. (1996). Indeed, vertical bargraph gauges were chosen for fuel and diesel exhaust fluid, as tanks that would be filled. Moreover, representations were

carefully chosen to minimize reading time. For example: clock was displayed digitally (clock read would be faster on digital than on analogue displays; Zeff, 1965) and speed was presented with a redundant speedometer (both digital and analogue, minimizing reading and off-road glance times compared to digital or analogue alone; François, Crave, Osiurak, Fort, & Navarro, 2017b).

- The layout used both location and size coding (Ross et al., 1996). Groups were visually separated according to the Gestalt Law of proximity (elements spatially close are perceived as belonging to each other) and boxes were used around groups to improve visual perception of grouping (ISO 9241-12, 1998).
- Guidelines also recommend to group information with their related controls (Stevens, Quimby, Board, Kersloot, & Burns, 2002). Spatial compatibility with command was respected: radio, gearbox and retarder information was located on the right; so as their associated stalks. Similarly, as cruise control switches are located on the left on the steering wheel, information were located on the left of the instrument cluster.
- Information was prioritized based on four criteria: relevance for the primary driving task, criticality, urgency and frequency of use (Stevens et al., 2002). Guidelines also recommend that information relevant to driving and prioritized information should be located closer to the normal line of sight (i.e. when the driver look at the road; Commission of the European Communities, 2007; Japan Automobile Manufacturers Association, 2004; Stevens et al., 2002). For this reason, primary driving information was presented at the top of the instrument cluster, contrary to secondary driving information and infotainment. Moreover, standards mention that the speedometer should be visible without head movement (ISO 4040, 2009). Therefore, speedometer was presented on the centre of the display and size coded to facilitate reading.

2.3. Participatory workshop (PDWS): a concept defined by a group of four drivers

2.3.1. *Participants*

Four truck drivers (all men, mean age: 36 years, SD: 12) took part in the workshop. They were recruited as temporary workers for the day of the workshop. The employment agency used for the recruitment is specialized for temporary workers in transport companies. They have a panel of truck drivers and logisticians who can be recruited on short contracts in case of an increase in business activity. Drivers were selected based on their professional activity (city or regional distribution), age (between 18 and 66 years old) and gender (men) to be representative of the French population of distribution drivers (Volvo Group Trucks Technology, 2015). Written informed consent and form of right to one's image were obtained from each participant. All participants held valid truck licenses. All participants were employed as distribution truck drivers, with a professional experience between one year and more than ten years. All reported normal or corrected-to-normal vision. All of them were used to interact with a smartphone.

Three Renault Trucks employees also participated to the workshop as facilitators. Their role was to drive the activities according to the planning, to help drivers to express themselves in a confident way and to ensure a positive working environment. Two of them were the HMI experts that defined the UCD concept.

The number of users involved was greater than the number of facilitators to avoid an imbalance situation. As reported by Sanders et al. (2010) for participatory design workshops, the group size can vary from two to many users. In this case study, the number of four drivers was chosen for practical reason (one driving simulator and two touchscreens available for all drivers).

2.3.2. Procedure

The workshop started with an informal moment around a coffee to get to know each other and 'break the ice'. To help participants to express freely: each one had a name tag on the shirt and it was required to speak informally. A presentation of the event was made by one facilitator. The goal was to be sure that the scope was clear for everyone and that everyone shared the same vocabulary.

Afterwards, a 'driver profile' questionnaire was filled one-to-one with each driver. General information was asked such as age, driving experience, carrier information, etc.

Then, participants were divided into two groups composed of two drivers and one facilitator. They first made a narrative activity to share their anecdotes and explain their daily work. A 'driver journey' was elaborated by each group based on the typical day of a truck driver. Facilitators asked drivers to describe a typical day from getting up in the morning to going to bed at night. A particular focus was put on the use of trucks HMI at each step of the day. Second, an activity of prioritization of information was made. Here, focus was on the instrument cluster. Drivers were asked to spontaneously generate information that they require to work as distribution driver. Information was written on a sticky note. Facilitators encouraged and relaunched them but did not influence the content of the information. After the spontaneous generation, drivers grouped the sticky notes on the wall in three groups of perceived importance. For each note, a color point was drawn to define if this information should: be always displayed, be in a page or a menu, or follow an alert strategy. To ensure that no information was involuntary omitted by drivers, a complete list was presented to them so that they could add information they would have forgotten. The objective of this activity was to concentrate on the information of the instrument cluster and to focus on drivers' needs and expectations. In addition, the data gathered from this activity is important knowledge for HMI designers. This was also a preparation in view of the next step, which was the definition of concepts. Always in groups, drivers started to define concept using a touchscreen (on a table at first because space was limited around the simulator). They could later upload their concept on the simulator and drive with it. During simulated driving on a highway environment, no specific instruction was given. Drivers could stop at any time, modify their concepts on the touchscreen and resume driving. They should include mandatory functions (the same as described above for the UCD concept). Each group generated two concepts. They decided when to stop, when they estimated that a concept

was complete. Facilitators were present to guide them, answer their questions and help them technically with the software if necessary, but they did not have a role of designer.

After lunch, participants were brought together for a 'pool and choose' session. The concepts generated were printed and hang on the wall. Each group explained their choices and strategies to the others. All participants could comment each concept.

On this basis, a common concept was built by the four drivers on the driving simulator. When they decided that the concept was complete, each driver performed a test-drive with the concept and validated that they were satisfied with it.

At the end of the workshop, they were asked to fill individually a feedback questionnaire. Seven points Likert scales measured four dimensions: user involvement (importance and personal relevance), user attitude, user perceived self-efficacy and desired participation. This questionnaire was used in the study of Hunton and Beeler (1997; items detailed in Appendix B) and based on the original questionnaire of Barki and Hartwick (1994).

2.3.3. Outcomes

2.3.3.1. Concept description

The PDWS concept contained 22 widgets (including three graphical separators; **Figure 3**). The size of seven widgets was modified by drivers (two of them were made bigger and five smaller). The percentage of white in the concept was 10.87%. Even if information chosen is very close to the UCD concept, widget representations and layout differed. Regarding information chosen, content is similar to the UCD concept, except one function that was not chosen ('radio preset') and three functions added ('odometer', 'air pressure level' and 'fuel endurance').



Figure 3. Concept resulting from the participatory workshop (PDWS concept).

Regarding widget representations, drivers chose a circular tachometer, horizontal gauges for fuel and diesel exhaust fluid, or added speed and distance to the 'adaptive cruise control time gap' widget. Regarding the layout, as for UCD, speed was presented in the center and other information was arranged around. However, specific information was prioritized. For example, the gearbox information was located at the top on the center of the cluster. Functional grouping was not always applied, as for cruise control widgets that were divided, half in the top right corner and other half in the left part of the cluster.

2.3.3.2. Driver involvement

Results showed that drivers felt involved and were very positive about their participation in trucks' HMI design (involvement scores: 6.22/7, 6.56/7, 6.44/7, 4.56/7; attitude scores: 6.50/7, 6.25/7, 5.50/7, 6.00/7; self-efficacy scores: 7/7, 7/7, 6/7, 5/7; desired participation scores: 7/7, 7/7, 7/7, 6/7).

2.4. Individual participatory design (PDInd): a concept specific to each driver

2.4.1. Participants

Twenty-seven truck drivers (all men, mean age: 38 years, SD: 9) participated in individual design sessions. All drivers were different from those who attended to the participatory workshop. They were recruited as temporary workers for one day (by the same temporary

employment agency used for the participatory workshop). As for the workshop, they were selected based on their activity (city or regional distribution), age (between 18 and 66 years old) and gender (men) to be representative of the French population of distribution drivers (Volvo Group Trucks Technology, 2015). Written informed consent and forms of right to one's image were obtained from each participant. All participants held valid truck licenses. All participants were employed as distribution truck drivers. 22% had between one and five years of professional experience, 37% between five and ten years and 41% has more than ten years of experience. All reported normal or corrected-to-normal vision. Eighty-nine percent of them used a smartphone. A Renault Trucks employee was also present during sessions as facilitator (this person already participated as facilitator at the participatory workshop).

2.4.2. Procedure

The procedure of the session was quite similar to that of the participatory workshop, with activities less, given that the total time of the session was half a day (versus one day for the workshop). Sessions were individual, meaning that for each session, the stakeholders were one driver and the facilitator (always the same person during all the individual sessions). The session started with an introduction to the theme around a coffee to 'break the ice'. Afterwards, a semi-directive interview was led to determine driver profile. Then, the design activity started. The driver installed directly at the driving simulator and created his own concept on the touchscreen. The driver could drive at any moment to self-assess his concept on a highway environment and without any specific instructions. The driver should include mandatory functions (the same as described above for the UCD concept). When the driver thought that the concept was completed, a debriefing was conducted with the facilitator to collect an explanation about his choices.

2.4.3. Outcomes

2.4.3.1. Concepts description

Twenty-seven concepts were collected (one per driver; examples in **Figure 4**). Concepts contained in average 17.85 widgets (SD= 2.77; graphical separators representing 2.09% of the total). The mean number of widgets for which the size was modified was 8.35 widgets per driver (SD=3.72). The percentage of white in the concept was 10.12% in average (SD=0.93).

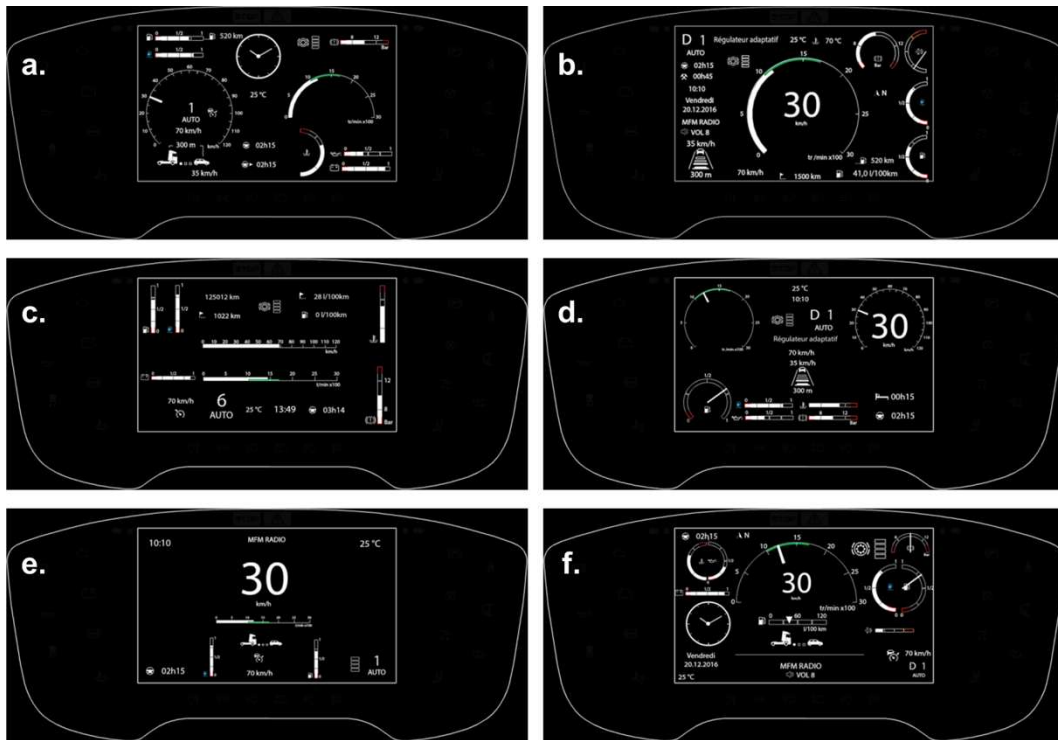


Figure 4. Six examples of concepts resulting from the individual participatory design sessions among the 27 collected (PDInd Concepts).

As the 27 concepts were composed from a base of more than 180 possible widgets choices and therefore a multitude of combinations (e.g. in terms of functionality, representation, location, size), each of the 27 concepts is not described in detail here but globally relative to the UCD and PDWS concepts. Among functionalities chosen by drivers, most of them are common with the UCD and PDWS concepts. However, some important differences appeared. Air pressure level was chosen individually by 89% of drivers, but was not present in the UCD concept. Similarly, oil level was chosen by 63% of drivers, but was not present in UCD and PDWS concepts. On the contrary, the 'break time' was presented in the UCD and PDWS concepts, but was chosen only by 33% of drivers individually. This is also the case for the odometer and fuel endurance information, which were chosen by drivers at the

workshop, but selected respectively by only 26% and 22% of drivers individually. Even more different, the 'radio preset' information was presented in the UCD concept and was not selected by any of the drivers individually. Regarding widgets representations, some clear preferences appeared. For example, the digital speedometer was chosen by 63% of drivers (22% chose an analogue speedometer and 11% a linear one). Similarly, to display the driver assistance mode, 74% of drivers chose the pictogram against 26% for the text representation (e.g. 'speed limiter'). For the clock, 78% of drivers chose a digital representation (11% the analogue clock). Regarding the retarder information, 67% of drivers chose to display the pictogram and the level of activation (19% only the pictogram and 15% only the level). Layout were diverse across drivers, however, we could distinguish global patterns. Forty-one percent of concepts were organized as the UCD and the PDWS concepts, around centered speed information (e.g. **Figures 4b, 4e and 4f**). Moreover, 26% of concepts were organized around two analogue counters (speed and tachometer) displayed horizontally (e.g. **Figures 4a and 4d**). The remaining 33% presented other layout patterns (e.g. **Figure 4c**).

2.4.3.2. Driver involvement

The scores of users' involvement – based on items on importance and personal relevance – were high ($M= 5.94/7$, $SD= 1.13$). Similarly, user attitude ($M= 6.06/7$, $SD= 0.84$), perceived self-efficacy ($M= 5.93/7$, $SD= 0.96$) and desired participation ($M= 6.56/7$, $SD= 0.75$) collected high scores.

3. Step 2: Concepts assessment

3.1. Participants

Participants were the same 27 truck drivers who participated in the individual participatory design sessions described in the previous design sections. Indeed, drivers were invited for one day. In the morning, they defined their own concept. In the afternoon, they assessed their concepts against both UCD and PDWS concepts on truck simulator with predefined

scenarios and tasks involving the use of the interfaces. All drivers were different from those who attended the participatory workshop.

3.2. Equipment

The assessment was led on the same driving simulator as the design sessions. The driving simulator was a fixed-base medium-fidelity driving simulator. The simulator was composed of a truck seat, two thirds of a real dashboard and a 65 inches plasma screen using Oktal SCANeR™ for traffic scenario and truck model. Original accelerator pedal, brake pedal and steering wheel of a Renault Trucks T were used. Concepts of instrument cluster were displayed on the 15.4 inches screen behind the steering wheel (height: 332mm, width: 207mm, resolution: 1920x1080).

3.3. Material

3.3.1. *Concepts*

The three concepts generated during the design sessions were compared (descriptions in step 1). Each driver therefore tested three concepts: the UCD concept, the PDWS concept and the personal concept they defined the same morning (i.e. PDInd concept). For the UCD and the PDWS concepts, the information given to the participant was that it was concepts created by other people without further detail.

3.3.2. *Driving scenario and tasks*

Each of the three driving scenarios lasted about 20 minutes. Participants had to respect the arrows displayed on the road screen to drive in the requested direction. The driving environment mixed 1/3 of country roads (speed limited to 70km/h) and 2/3 of city roads (speed limited to 50km/h), with a random traffic around the vehicle. As this study focused on medium duty vehicles (mainly intended for a regional application), no highway task was proposed for the sake of ecological validity. Along the scenarios, tasks were enunciated through the radio. Tasks were arranged at different locations on the course. Participants verbally reported the answers or completed the required action, referring to the dynamically

updating dashboard display. Eleven different tasks were replicated twice per scenario (**Table 1**). The goal with these tasks was to put the driver in a situation of use of the interfaces. The tasks were chosen to be realistic and with different level of interaction complexity. All the tasks could be carried out with all the concepts.

Task ID	Task instruction	Expected answer
Task 1	Which gear is engaged?	Verbal answer: e.g. 5
Task 2	What is your current speed?	Verbal answer: e.g. 45 km/h
Task 3	Do you still have at least 1/4th of gasoline?	Verbal answer: yes or no
Task 4	Set the radio station to ...	Action: turn the thumbwheel until reaching the required station
Task 5	Do you drive above or below 30 km/h?	Verbal answer: above or below
Task 6	Set your cruise control to 70 km/h.	Action: activate the cruise control, set the target speed with plus and minus switches
Task 7	Set your speed limiter to 50 km/h.	Action: activate the speed limiter, set the target speed with plus and minus switches
Task 8	Is the retarder activated?	Verbal answer: yes or no
Task 9	What is your driving time?	Verbal answer: e.g. 03:02
Task 10	What time is it?	Verbal answer: e.g. 14:45
Task 11	Is the speed limiter activated?	Verbal answer: yes or no

Table 1. Instructions and expected answer of the eleven tasks performed during the test drive.

3.3.3. Questionnaires

Three questionnaires were chosen to evaluate usability. First, the Rating Scale Mental Effort (RSME) was used to measure subjective mental workload (see Zijlstra & Van Doorn, 1985 for details). Drivers had to tick the graduated line of 150mm to rate their perceived mental effort required (the measurement in mm giving a score over 150). Second, the System Usability Scale was used as a global indication of usability (see Brooke, 1986 for details). Ten items from 'strongly disagree' to 'strongly agree' gave a global score of usability over 100 points. Third, a questionnaire aimed at measuring in more detail the five constructs of usability, as defined by Nielsen (2012). It consisted of a five items questionnaire (one per construct: learnability, efficiency, memorability, errors and satisfaction) with five points Likert

scales, from 'one = strongly disagree' to 'five = strongly agree' (see François et al., 2017b for details).

Regarding acceptance, the acceptance scale of Van der Laan, Heino and De Waard (1997) measured two dimensions of acceptance: utility and satisfaction. Both scores are determined thanks to a ten items questionnaire. All these questionnaires were presented after each test drive carried out with the concept tested.

At the end of the experiment, driver satisfaction was investigated in a relative way (after the driver interacted with the three concepts). The order of preference (from one to three) was collected orally. One represented the most satisfying concept and three represented the least satisfying concept. A satisfaction score was also collected for each concept using an eleven points Likert scale (zero meaning 'not satisfying at all' and ten meaning 'very satisfying').

The interest to evaluate concepts thanks to several questionnaires was to explore the different aspects of usability and acceptance. Indeed, the SUS measures the global usability of the system. The RSME and Nielsen's scale measure sub-dimensions of usability, as described in the introduction section. The Van der Laan Scale addresses the notion of acceptance through two widely recognized sub-dimensions (i.e. utility and satisfaction). The order of preference was complementary to this measure in order to measure satisfaction in a more relative way. Secondly, to assess if results were consistent between questionnaires was also significant to ensure internal validity. The choice of the questionnaires was made according to their length and understandability. The goal was to have it easy to follow and easy to respond to. For each questionnaire, the scores for the three concepts were compared using a Friedman test. If a statistical difference was reported, pairwise comparisons were performed. A Holm-Bonferroni correction was applied to the obtained p-values in order protect against Type I error (Holm, 1979). The global hypothesis was that participatory design would increase usability and acceptance compared to user-centered design. In this sense, differences were expected for all questionnaires when testing the pairwise comparisons between UCD - PDWS and UCD - PDInd.

3.4. Procedure

Participants spent half of the day designing their own concept before this phase. The assessment started after a lunch break (more than 30 minutes) to prevent driver's weariness. At the beginning of the assessment phase, the procedure and instructions were exposed. The test was composed of three test drives (one per concept tested). Before each test drive, participants were given a ten minutes trial to familiarize with the tested concept. They could drive and interact freely with the concept, without specific instruction. During each test drive, tasks instructions were randomly announced through the radio. The driver could then give his answer aloud or complete the required action. After each test drive, usability and acceptance questionnaires were filled up by the driver regarding the tested concept. At the end of the experiment, participants were asked to report their preferences, by providing the order of preference and assigning satisfaction scores to each concept.

Each participant was tested individually and experienced all conditions. The order in which the experimental conditions were presented was counterbalanced by following a Latin square crossing the three concepts. The total test duration was approximately three hours. Drivers could take a break after each of the first two test drive.

4. Results

4.1. Usability

4.1.1. *Perceived mental effort*

A Friedman test was run to determine if there were differences regarding the perceived mental effort required to interact with the three concepts (**Figure 5**). Perceived mental effort was statistically significantly different between the three concepts ($\chi^2(2) = 11.370, p = .003$). Pairwise comparisons were performed using separate Wilcoxon signed-rank tests. A Holm-Bonferroni adjustment was applied to the p-values of the tests. They revealed statistically significant differences in RSME scores between UCD ($Mdn = 26$) and PDWS concepts ($Mdn =$

38) ($Z= 3.01$, $p= .003$) and between PDInd ($Mdn= 28$) and PDWS concepts ($Z= 2.34$, $p= .019$), but not between UCD and PDInd concepts.

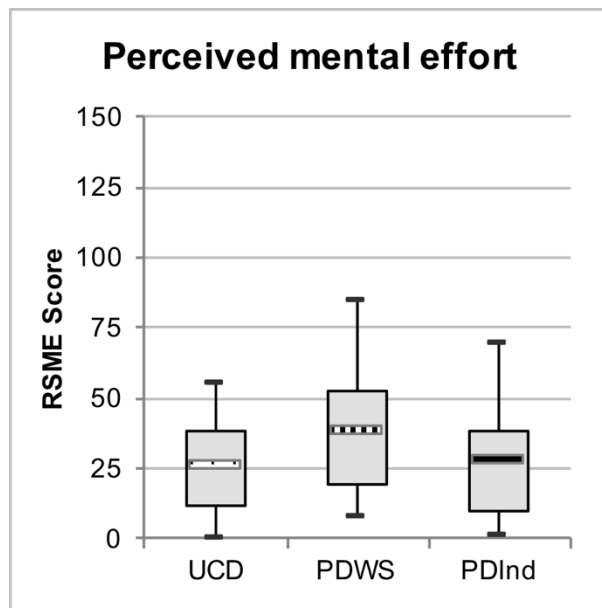


Figure 5. Results to the RSME questionnaire for the three concepts. Errors bars represent the minimum and maximum values.

4.1.2. System usability scale

A Friedman test examined differences in SUS scores (**Figure 6**). The differences were not statistically significant between the three concepts.

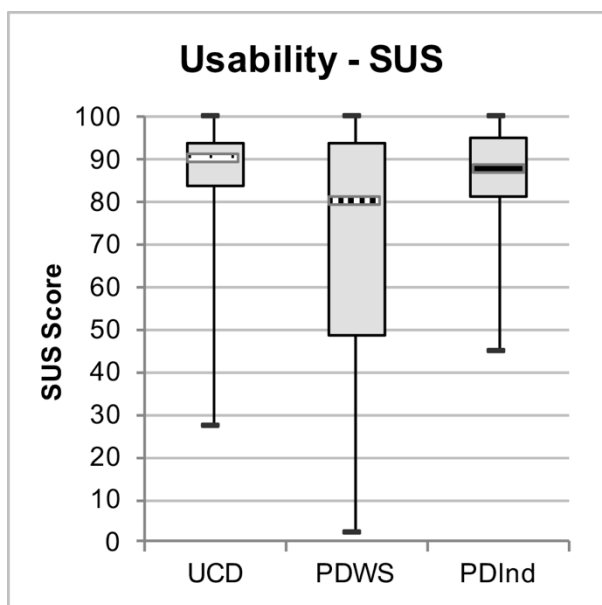


Figure 6. Results to the System Usability Scale (SUS) for the three concepts. Errors bars represent the minimum and maximum values.

4.1.3. Usability questionnaire

Friedman tests and pairwise comparisons were led for each dimension of the questionnaire for the three concepts using Wilcoxon tests (**Figure 7**). A Holm-Bonferroni adjustment was applied to the p-values of the tests. Friedman tests revealed significant differences between the three concepts for all dimensions (learnability: $\chi^2(2)= 13.000$, $p = .002$; efficiency: $\chi^2(2)= 18.778$, $p < .001$; memorability: $\chi^2(2)= 11.485$, $p = .003$; errors: $\chi^2(2)= 11.855$, $p = .003$; and satisfaction: $\chi^2(2)= 6.583$, $p = .037$). The UCD concept was scored significantly better than the PDWS concept on three of the five dimensions (efficiency: $M= 4.30$ and $M= 3.44$, $Z= 2.88$, $p = .004$; memorability: $M= 4.56$ and $M= 3.81$, $Z= 2.75$, $p = .006$; and errors: $M= 4.19$ and $M= 3.41$, $Z= 2.79$, $p = .005$). Similarly, drivers scored significantly better the PDInd concept than the PDWS concept on all five dimensions (learnability: $M= 4.78$ and $M= 3.78$, $Z= 3.28$, $p = .001$; efficiency: $M= 4.48$ and $M= 3.44$, $Z= 3.41$, $p < .001$; memorability: $M= 4.52$ and $M= 3.81$, $Z= 2.58$, $p = .010$; errors: $M= 4.22$ and $M= 3.41$, $Z= 2.77$, $p = .006$; satisfaction: $M= 4.30$ and $M= 3.59$, $Z= 2.35$, $p = .019$). No significant difference was found between the UCD and the PDInd concepts.

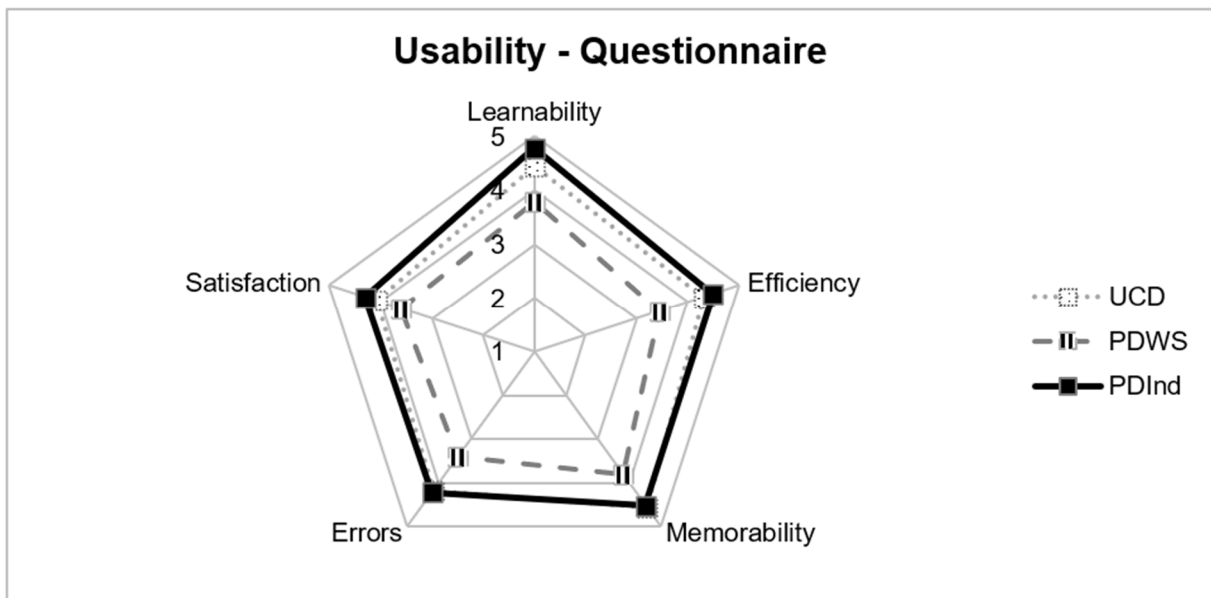


Figure 7. Results to the usability questionnaire for the three concepts.

4.2. Acceptance

4.2.1. Acceptance scale

Friedman tests were run to determine if there were statistical differences of utility and satisfaction between the three concepts (**Figure 8**). Pairwise comparisons were performed using Holm-Bonferroni corrected Wilcoxon tests. Regarding utility, a statistically significant difference was found between the three concepts ($\chi^2 (2) = 8.37, p = .015$). Pairwise comparisons revealed a statistically significant difference in utility between PDInd ($M = 1.29$) and PDWS concepts ($M = 0.64$) ($Z = 3.33, p = .001$). Differences between the UCD ($M = 1.01$) and the PDWS concepts and between UCD and PDInd concepts were not statistically significant. Regarding satisfaction, difference between the three concepts was significant ($\chi^2 (2) = 6.61, p = .037$). Pairwise comparisons showed that the difference between PDInd ($M = 1.23$) and PDWS scores ($Z = 3.24, p = .001$) was significant. No significant difference was observed, neither between UCD and PDInd, nor between UCD and PDWS.

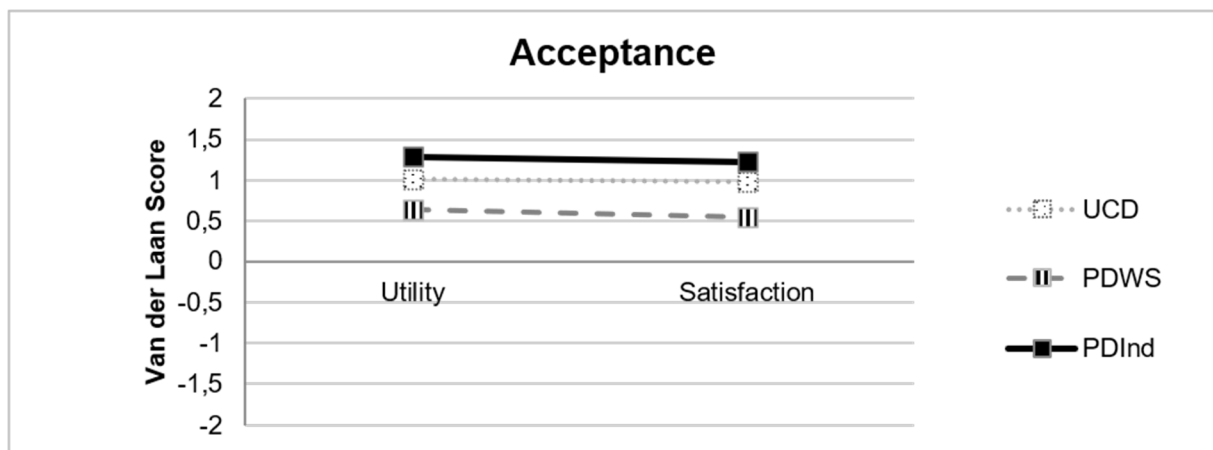


Figure 8. Van der Laan et al. (1997) Acceptance Scale average scores for the three concepts.

4.2.2. Global satisfaction

Regarding drivers' preference, 52% of drivers ranked the PDInd concept at the first place (against 33% for the UCD concept and 15% for the PDWS concept) (**Figure 9**). The difference of rank was significant between the three concepts ($\chi^2 (2) = 7.41, p = .025$). Multiple pairwise Wilcoxon tests revealed that drivers significantly preferred the PDInd concept ($Mdn = 1$) to the PDWS concept ($Mdn = 3$) ($Z = 2.52, p = .012$). The UCD concept

(*Mdn*= 2), rated in between the PDWS concept (*Mdn*= 3) and the PDInd concept (*Mdn*= 1), did not significantly differ from the two other concepts.

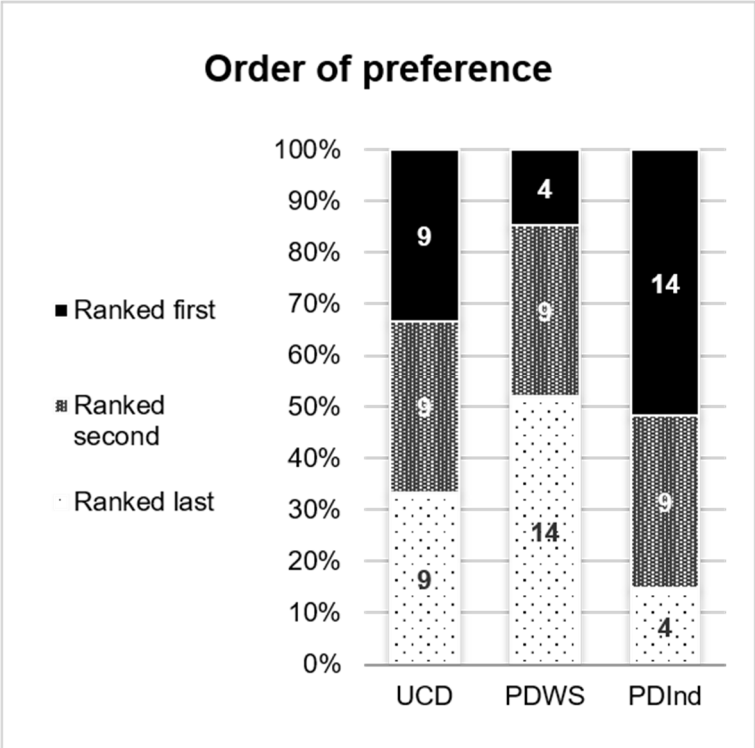


Figure 9. Percentage for each rank of the order of preference for the three concepts (from first rank: preferred to last rank: least preferred).

The satisfaction scores (between zero and ten) were not significantly different between the three concepts ($\chi^2 (2) = 2.558, p = .278$) (Fig. 10). Descriptively, the UCD concept collected better scores (*Mdn*= 7.5), followed by the PDInd concept (*Mdn*= 7), then by the PDWS concept (*Mdn*= 6).

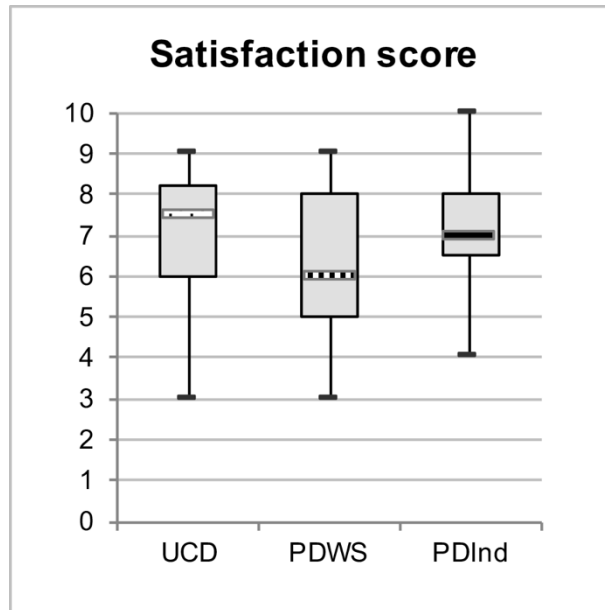


Figure 10. Medians of the satisfaction scores for the three concepts. Errors bars represent the minimum and maximum values.

5. Discussion

5.1. Findings

5.1.1. RQ1: Do instrument cluster concepts resulting from user-centered design differ from those resulting from participatory design in terms of usability and acceptance?

Previous studies reported two benefits from participatory design. First, using tacit knowledge as input to design, participatory design would result in more usable systems than user-centered design (Spinuzzi, 2005). Second, highlighting the tacit and latent needs of users in a participatory design would lead to more accepted systems (Sanders, 2002). Based on this, our hypothesis was that the outcome from user-centered design would be less usable and accepted than both participatory design outcomes. However, results were different when comparing the user-centered design (UCD) concept with the concept of the participatory workshop (PDWS) and the user-centered design concept with individual concepts (PDInd).

		UCD vs PDWS	UCD vs PDInd	PDWS vs PDInd	
Usability	Perceived mental effort (RSME)	UCD better	ns	PDInd better	
	Global usability (SUS)	ns	ns	ns	
	Usability dimensions (questionnaire based)	Learnability	ns	ns	PDInd better
		Efficiency	UCD better	ns	PDInd better

	on Nielsen criteria)	Memorability	UCD better	ns	PDInd better
		Errors	UCD better	ns	PDInd better
		Satisfaction	ns	ns	PDInd better
Acceptance	Acceptance (Van der Laan Scale)	Utility	ns	ns	PDInd better
		Satisfaction	ns	ns	PDInd better
	Global satisfaction	Order of preference	ns	ns	PDInd better
		Satisfaction score	ns	ns	ns

Table 2. Summary of the results for each variable for the differences between the user-centered design (UCD), the participatory design workshop (PDWS) and the individual participatory design (PDInd) concepts, ns = non-significant

Findings revealed that the concept generated with a user-centered design process was perceived as more usable than the concept of the participatory workshop (**Table 2**). The perceived mental effort was significantly lower with the UCD concept and global usability was scored higher. The UCD concept was also scored better than the PDWS concept on efficiency, memorability and errors. Regarding acceptance, differences between both concepts were not significant. Even if it was not significant, the UCD concept collected better descriptive satisfaction scores and order of preference at the end of the study. The PDWS concept was ranked first by 15% of drivers only, with a median satisfaction score of 6/10. For its part, the UCD concept was ranked first by 33% of drivers and collected the best satisfaction score (*Mdn*= 7.5/10).

On the contrary, results showed that there were no significant difference on all measures between the UCD concept and the PDInd concept. Both concepts were perceived as requiring few mental efforts, with good overall usability (as well as all sub-dimensions). Acceptance was also good for both concepts, with slightly higher utility and satisfaction scores for the individual concepts than for the UCD concept (with no significant difference). This effect was also found in the order of preference and the satisfaction scores collected at the end of the evaluation. The individual concept was chosen first by more than half of the drivers (52%) with a median satisfaction score of 7/10. The UCD concept was ranked first by one third of drivers (with a slightly higher rating: *Mdn*= 7.5/10). Eighty-five percent of drivers chose their personal concept in first or second position of order of preference, against 67% for the UCD concept. Even if these effects are not significant, this preference for the

individual concept has been found in all measures of satisfaction whatever the questionnaire ($M= 4.3$ against $M= 4.1$ at the satisfaction dimension of the usability questionnaire; $M= 1.28$ against $M= 0.98$ for the satisfaction dimension of the Van der Laan et al. questionnaire).

The first consideration regarding results is that usability and acceptance gaps were not linked to the level of driver involvement, but to the implemented approach. Indeed, differences with the UCD concept were not consistent between the two PD approaches. The 'pragmatic' benefit of participatory design (Carroll & Rosson, 2007) would then be relative to the participatory method employed. Second, these results highlighted that experts can create more usable concepts than a group of users in a workshop and as usable and accepted than concepts created individually by drivers. Sanders (2002) argued that user-centered design would lack access to users' implicit knowledge. However, without accessing to drivers' implicit knowledge, the UCD concept was perceived as usable by drivers. The application of human-factors guidelines and a design centered on usability aspects would therefore also be effective to create usable interfaces. Similarly, the good results of acceptance for the UCD concept revealed that designers can address correctly users needs and expectations. Indeed, drivers preferred an instrument cluster created for them by experts than an instrument cluster created for them by drivers. Contrary to what Sanders and Stappers (2008) stated, "user-centered design is not dead" and can address the 'scale or the complexity of the challenges we face today'. However, compared to individual concepts, the UCD concept orders of preference were more distributed (33% first rank, 33% second rank, 33% third rank). This would suggest that the concept conceived by experts would be less univocal in terms of satisfaction.

5.1.2. RQ2: Is there a usability and acceptance gap between outcomes from two participatory design methods?

Results showed a marked difference between the individual concept and the concept resulting from the participatory workshop (**Table 2**). On all measurements carried out, the individual concept was perceived as more usable: perceived mental effort was significantly

lower and each of the five dimensions of usability collected better scores. Regarding concepts acceptance, individual concepts were perceived as more useful and satisfying than the concept generated from the participatory workshop. Findings also revealed a strong preference for the individual concept compared to the PDWS concept: more than half of participants ranked their own concept as the better concept, while more than half of participants ranked the workshop concept as the worse concept. Similarly, although the difference was not significant, personal concepts were scored better than the PDWS concept concerning satisfaction (respectively *Mdn*= 7 and *Mdn*= 6).

The results are very consistent between all measurements: drivers perceive their concept as easier to use and more acceptable than a concept created for them by a group of drivers. This result contradicts the idea that the process of group interaction would lead to more insightful and powerful outcomes than the sum of individual perspectives (Sanoff, 2007). Consensus building and collective intelligence (Sanoff, 2007) would not lead to more usable and accepted concepts. Fan and Poole (2006) proposed an explanation: group design would consider more group norms and stereotypes than individual needs. The subset of four users would have failed to translate the needs of actual end users (Mugge, Schoormans & Schifferstein, 2009). On the contrary, individual participatory design sessions would allow drivers to conceive easy to use dashboards that they intend to use. These results are in line with the study of Normark and Gustafsson (2014) on cars cockpit personalization. The argument that users do not always know what they want (Madrigal & McClain, 2011) was not demonstrated in this study. On the contrary, the design outcome of an individual participatory process closely matches the end user's individual needs and taste (Mugge et al 2009). Individual participatory design could thus be a promising approach towards interfaces adapted to each user, including the users with specific preferences (Huh & Ackerman, 2009).

5.2. Limitations and perspectives

Some limitations to these results can be pointed out. First, findings showed that results depended of the design approach implemented, whatever the level of user involvement. Therefore, our results are not generalizable to user-centered design or participatory design in general. Indeed, there could have been several other ways to collect a user-centered design outcome on the same design case (e.g. with others or more designers, more iterations, more drivers to test concepts). Similarly, there is variety of ways to achieve a participatory design outcome (Bratteteig & Wagner, 2016) and other participatory approaches could have been implemented (e.g. different roles for users and designers, other design activities, a higher number of drivers involved). This study, although it does not compare all the approaches for each level of involvement, has the merit of investigating different approaches rigorously on the same case of design and with the same tools. This meets a need of evidence and strict comparisons between design processes (Bratteteig & Wagner, 2016; Francois et al., 2017a).

Second, we demonstrated that the outcome of the participatory workshop was found less usable and accepted. However, we tested the resulting concept and not the method or another type of outcomes such as new knowledge, skills and collaborations (Bratteteig & Wagner, 2016). The participatory workshop brought a lot of narrative information about the activities and needs of drivers. Even if the resulting concept is not as efficient as expected, this method can be envisaged differently, for example as an input to the design phase by the experts in a UCD (as proposed in the ISO/TR 16982, 2002).

Third, findings of this study open perspectives for truck dashboard personalization. Today, in some trucks, drivers can choose between several pre-defined layout or display favorite information in reserved areas. This allows to offer customization options while mastering regulatory aspects (e.g. display of warning lights). From a regulatory point of view, it would be possible today to implement personalization options close to the Individual Participatory method presented in this study, if the mandatory information is displayed. However, other aspects have to be investigated between letting drivers on the road with their own instrument cluster. Among them, other assessment criteria should be examined, such as the impact on

driver distraction, efficiency, or driving performance. In addition to this subjective assessment, actual usability evaluation with objective measures should be added (e.g. errors, task completion times).

It would be important to explore the reasons for the differences between the two participatory methods on the subjective quality of the results. Indeed, the good results for the individual concepts could rely on a drivers' over-estimation of their production. People value choice (Leotti, Iyengar, & Ochsner, 2010) and choice-making would even have an impact on the subjective experience through an activation in brain regions associated with motivation and reward (Leotti & Delgado, 2011). In addition, there was in this study a short delay between the design activity and the assessment of usability and acceptance. It would be essential to investigate the dynamic of these criteria on long term use. For example, Nurkka (2016) showed that owners of connected watch continue to use the customization features over six months after purchase. The usability and acceptance of their concepts could thus have evolved.

6. Conclusion

In this simulator study, drivers compared three concepts of trucks instrument cluster: a concept created in a user-centered design process (defined by HMI experts and assessed by drivers), a concept created during a participatory workshop (with several drivers) and their own concept (defined in an individual participatory design session). After a test drive interacting with each concept, they filled out usability and acceptance questionnaires. The key findings of this study were the followings:

- The concept resulting from the user-centered design process was not significantly different than the individual concepts in terms of usability and acceptance
- The concept generated during the participatory workshop was significantly perceived as less usable and accepted than both UCD concept and individual concepts

- The individual participatory sessions resulted in concepts perceived as very usable, acceptable and satisfying
- Even if satisfaction was slightly lower than for individual concepts, the user-centered design concept was found very usable and acceptable

These findings question benefits attributed globally to PD and encourage to further explore focusing the different PD approaches. Moreover, these results show that a design by experts *for* and *with* users can produce usable and accepted outcomes.

7. Acknowledgement

This study was supported by the LABEX CORTEX (Grant ANR-11-LABX-0042) of Université de Lyon, within the program “Investissements d’Avenir” (Grant ANR-11-IDEX-0007), operated by the French National Research Agency (ANR). This work has also been made possible through a CIFRE PhD convention from the ANRT (ANRT-2013/1405), funded by the French Ministry of Higher Education and Research. The authors wish to thank Clarisse Chervet and Ghislaine Goullioud for their help and their insightful advices.

8. References

- Abelein, U., Sharp, H., & Paech, B. (2013). Does involving users in software development really influence system success?. *IEEE software*, 30(6), 17-23.
- Adell, E. (2010). Acceptance of driver support systems. In *Proceedings of the European conference on human centered design for intelligent transport systems*(Vol. 2, pp. 475-486).
- Barki, H., & Hartwick, J. (1994). Measuring user participation, user involvement, and user attitude. *MIS quarterly*, 59-82.
- Bekker, M., & Long, J. (2000). User involvement in the design of human-computer interactions: Some similarities and differences between design approaches. In *People and Computers XIV—Usability or Else!* (pp. 135-147). Springer, London.
- Bjögvinsson, E., Ehn, P., & Hillgren, P. A. (2012). Design things and design thinking: Contemporary participatory design challenges. *Design issues*, 28(3), 101-116.
- Bratteteig, T., & Wagner, I. (2016, August). What is a participatory design result?. In *Proceedings of the 14th Participatory Design Conference: Full papers-Volume 1* (pp. 141-150). ACM.
- Bruno, F., & Muzzupappa, M. (2010). Product interface design: A participatory approach based on virtual reality. *International journal of human-computer studies*, 68(5), 254-269.
- Brooke, J. (1986). System usability scale (sus): A quick-and-dirty method of system evaluation user information. Digital equipment co ltd. *Reading, UK*, 1-7.
- Camargo, M., Wendling, L., & Bonjour, E. (2014). A fuzzy integral based methodology to elicit semantic spaces in usability tests. *International Journal of Industrial Ergonomics*, 44(1), 11-17.
- Carroll, J. M. (1996). Encountering others: Reciprocal openings in participatory design and user-centered design. *Human-Computer Interaction*, 11(3), 285-290.
- Carroll, J. M., & Rosson, M. B. (2007). Participatory design in community informatics. *Design studies*, 28(3), 243-261.
- Chowdhury, A., Karmakar, S., Reddy, S. M., Ghosh, S., & Chakrabarti, D. (2014). Usability is more valuable predictor than product personality for product choice in human-product physical interaction. *International Journal of Industrial Ergonomics*, 44(5), 697-705.
- Cinto, T., Avila, I., & de Souza, F. (2015). Inclusive Participatory Workshop: Accessible Iconography Design. *International Journal of Digital Information and Wireless Communications*, 5(2), 158-165.
- Clement, A., & Van den Besselaar, P. (1993). A retrospective look at PD projects. *Communications of the ACM*, 36(6), 29-37.
- Commission of the European Communities (2007). *Commission Recommendation on Safe and Efficient In-Vehicle Information and Communication Systems: Update of the European Statement of Principles on Human Machine Interface*. Official Journal of the European Union.
- Damodaran, L. (1996). User involvement in the systems design process-a practical guide for users. *Behaviour & information technology*, 15(6), 363-377.
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. *Management science*, 35(8), 982-1003.
- Dickinson, A., Lochrie, M., & Egglestone, P. (2015, July). DataPet: Designing a participatory sensing data game for children. In *Proceedings of the 2015 British HCI Conference* (pp. 263-264). ACM.
- Eason, K. D. (1995). User-centered design: for users or by users?. *Ergonomics*, 38(8), 1667-1673.
- Fan, H., & Poole, M. S. (2006). What is personalization? Perspectives on the design and implementation of personalization in information systems. *Journal of Organizational Computing and Electronic Commerce*, 16(3-4), 179-202.
- François, M., Crave, P., Osiurak, F., Fort, A., & Navarro, J. (2017b). Digital, analogue, or redundant speedometers for truck driving: Impact on visual distraction, efficiency and usability. *Applied Ergonomics*, 65, 12-22.
- François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2017a). Automotive HMI design and participatory user involvement: review and perspectives. *Ergonomics*, 60(4), 541-552.

- Gkouskos, D., Normark, C. J., & Lundgren, S. (2014). What drivers really want: Investigating dimensions in automobile user needs. *International Journal of Design*, 8(1).
- Harvey, C., Stanton, N. A., Pickering, C. A., McDonald, M., & Zheng, P. (2011). Context of use as a factor in determining the usability of in-vehicle devices. *Theoretical issues in ergonomics science*, 12(4), 318-338.
- Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian journal of statistics*, 65-70.
- Huang, H., Yang, M., & Lv, T. (2018). Ergonomic analysis of washing machines for elderly people: A focus group-based study. *International Journal of Industrial Ergonomics*, 68, 211-221.
- Huh, J., & Ackerman, M. S. (2009, April). Designing for all users: including the odd users. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems* (pp. 2449-2458). ACM.
- Hunton, J. E., & Beeler, J. D. (1997). Effects of user participation in systems development: a longitudinal field experiment. *Mis Quarterly*, 359-388.
- International Organization for Standardization (1998). *ISO 9241-12 - Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 12: Presentation of information*. International Organization for Standardization.
- International Organization for Standardization (2002). *ISO/TR 16982 - Ergonomics of human-system interaction — Usability methods supporting human-centered design*. International Organization for Standardization.
- International Organization for Standardization (2009). *ISO 4040 - Road vehicles -- Location of hand controls, indicators and tell-tales in motor vehicles*. International Organization for Standardization.
- International Organization for Standardization (2010). *ISO 9241-210 - Ergonomics of human-system interaction – Human-centered design for interactive systems*. International Organization for Standardization.
- Japan Automobile Manufacturers Association. (2004). Guideline for in-vehicle display systems, Version 3.0. Retrieved July, 18, 2017.
- Khaled, R., & Vasalou, A. (2014). Bridging serious games and participatory design. *International Journal of Child-Computer Interaction*, 2(2), 93-100.
- Kim, S., Dey, A. K., Lee, J., & Forlizzi, J. (2011, May). Usability of car dashboard displays for elder drivers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 493-502).
- Kujala, S. (2003). User involvement: a review of the benefits and challenges. *Behaviour & information technology*, 22(1), 1-16.
- Lamas, R., Burnett, G., Cobb, S., & Harvey, C. (2015). Please let me in: a participatory workshop approach to the design of a driver-to-driver communication device. *Procedia Manufacturing*, 3, 3309-3316.
- Leotti, L. A., & Delgado, M. R. (2011). The inherent reward of choice. *Psychological science*, 22(10), 1310-1318.
- Leotti, L. A., Iyengar, S. S., & Ochsner, K. N. (2010). Born to choose: The origins and value of the need for control. *Trends in cognitive sciences*, 14(10), 457-463.
- Lindsay, S., Jackson, D., Schofield, G., & Olivier, P. (2012, May). Engaging older people using participatory design. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 1199-1208). ACM.
- Liu, Y. C., & Ko, C. H. (2017, July). The Effects of Website White Space on Middle-Aged Users. In *International Conference on Applied Human Factors and Ergonomics* (pp. 538-546). Springer, Cham.
- Madrigal, D., & McClain, B. (2011). *The Dangers of Design by User*. Retrieved from <http://www.uxmatters.com/mt/archives/2011/03/the-dangers-of-design-by-user.php>
- Marcus, A. (2004). The next revolution: vehicle user interfaces. *Interactions*, 11(1), 40-47.
- Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2009). Incorporating consumers in the design of their own products. The dimensions of product personalisation. *CoDesign*, 5(2), 79-97.

- Naweed, A., Ward, D., Gourlay, C., & Dawson, D. (2018). Can participatory ergonomics process tactics improve simulator fidelity and give rise to transdisciplinarity in stakeholders? A before–after case study. *International Journal of Industrial Ergonomics*, *65*, 139-152.
- Nielsen, J. (2012). *Usability 101: Introduction to Usability*. Nielsen Norman Group. Retrieved from <https://www.nngroup.com/articles/usability-101-introduction-to-usability/>
- Normark, C. J., & Gustafsson, A. (2014). Design and evaluation of a personalisable user interface in a vehicle context. *Journal of Design Research*, *12*(4), 308-329.
- Nurkka, P. (2016, December). Customization in long-term use: the case of the sports watch. In *Proceedings of the 15th International Conference on Mobile and Ubiquitous Multimedia* (pp. 5-10). ACM.
- Österman, C., Berlin, C., & Bligård, L. O. (2016). Involving users in a ship bridge re-design process using scenarios and mock-up models. *International Journal of Industrial Ergonomics*, *53*, 236-244.
- Palaigeorgiou, G., Triantafyllakos, G., & Tsinakos, A. (2011). What if undergraduate students designed their own web learning environment? Exploring students' web 2.0 mentality through participatory design. *Journal of Computer Assisted Learning*, *27*(2), 146-159.
- Ross, T., Midtland, K., Fuchs, M., Pauzié, A., Engert, A., Duncan, B., & May, A. (1996). HARDIE design guidelines handbook: human factors guidelines for information presentation by ATT systems. *Commission of the European Communities, Luxembourg*.
- SAE. (2009). *J1138 - Design Criteria - Driver Hand Controls Location for Passenger Cars, Multipurpose Passenger Vehicles, and Trucks (10 000 GVW and Under)*. SAE International
- Sanders, E. B. N. (2002). From user-centered to participatory design approaches. *Design and the social sciences: Making connections*, *1*(8).
- Sanders, E. B. N., Brandt, E., & Binder, T. (2010, November). A framework for organizing the tools and techniques of participatory design. In *Proceedings of the 11th biennial participatory design conference* (pp. 195-198). ACM.
- Sanders, E. B. N., & Stappers, P. J. (2008). Co-creation and the new landscapes of design. *Co-design*, *4*(1), 5-18.
- Sanoff, H. (2007). Special issue on participatory design. *Design Studies*, *28*(3), 213-215.
- Seim, R., & Broberg, O. (2010). Participatory workspace design: A new approach for ergonomists?. *International Journal of Industrial Ergonomics*, *40*(1), 25-33.
- Sleeswijk Visser, F., Stappers, P. J., Van der Lugt, R., & Sanders, E. B. (2005). Contextmapping: experiences from practice. *CoDesign*, *1*(2), 119-149.
- Spinuzzi, C. (2005). The methodology of participatory design. *Technical communication*, *52*(2), 163-174.
- Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). *Design guidelines for safety of in-vehicle information systems*. TRL Limited.
- Tang, P., Sun, X., & Cao, S. (2020). Investigating user activities and the corresponding requirements for information and functions in autonomous vehicles of the future. *International Journal of Industrial Ergonomics*, *80*, 103044.
- Van Der Laan, J. D., Heino, A., & De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies*, *5*(1), 1-10.
- Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science*, *46*(2), 186-204.
- Volvo Group Trucks Technology (2015). *Identify and specify MPV HMI Context of use*. Internal report: unpublished.
- Zeff, C. (1965). Comparison of conventional and digital time displays. *Ergonomics*, *8*(3), 339-345.
- Zijlstra, F., & van Doorn, L. (1985). The construction of a scale to measure subjective effort. In *Technical Report*. Delft University of Technology.