Level of driver involvement in trucks human-machine interfaces design : effects on usability, distraction and acceptance

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Level of driver involvement in trucks human-machine interfaces design : effects on usability, distraction and acceptance

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Level of driver involvement in trucks human-machine interfaces design: effects on usability, distraction and acceptance

Niveau d'implication des conducteurs dans la conception d'interfaces homme-machine poids lourd : effets sur l'utilisabilité, la distraction et l'acceptation

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> "You have brains in your head
> You have feet in your shoes
> You can steer yourself any direction you choose."
> Dr. Seuss (1990) *Oh, the Places You'll Go!* Random House

“If I had asked people what they wanted,
they would have said faster horses.”
Henry Ford

Niveau d’implication des conducteurs dans la conception d’interfaces homme-machine poids lourd : effets sur l’utilisabilité, la distraction et l’acceptation

Résumé

Le processus de conception des interfaces homme-machine poids-lourd a été adapté afin de répondre aux enjeux humains et sécuritaires. Il est désormais largement admis que la participation des utilisateurs dans le processus de conception est un apport précieux. Actuellement dans l'industrie, les utilisateurs sont principalement impliqués lors des étapes d'analyse et d'évaluation des concepts, ces derniers étant définis par des professionnels. Cependant, la littérature dans d'autres domaines rapporte des bénéfices d’une autre forme d’implication des utilisateurs : la conception participative. Dans ce processus de conception, les utilisateurs sont impliqués tout au long du développement des produits, et en particulier lors de la définition des concepts. La conception participative permettrait un meilleur accès aux besoins des utilisateurs, à leurs attentes, et à leurs connaissances tacites. Ce projet a pour objectif d’étudier comment le niveau d’implication des conducteurs dans le processus de conception impacte l’utilisabilité, la distraction et l'acceptation des interfaces homme-machine poids-lourd. Après une analyse préalable du contexte d'utilisation, trois processus de conception de tableaux de bord ont été menés en parallèle à l’aide d’un équipement tactile. Les résultats de ces trois processus, ayant des niveaux d’implication différents, ont été évalués et comparés dans une expérience sur simulateur de conduite. Les résultats ne permettent pas de démontrer qu’une conception participative a un impact significatif sur l’utilisabilité, la distraction et l’acceptation. Cette thèse se conclut par des recommandations aux praticiens et des perspectives de recherche.

Mots-clés

Interfaces homme-machine ; implication des utilisateurs ; conception centrée sur l’utilisateur ; conception participative.

Level of driver involvement in trucks human-machine interfaces design: effects on usability, distraction and acceptance

Abstract

The design process of trucks human-machine interfaces has been adapted to address human factors and road safety issues. It is now widely accepted that user involvement in the design process is valuable. Currently in industry, users are mainly involved in the stages of analysis and evaluation of concepts, the latter being defined by professionals. However, the literature in other fields reports benefits of a broader form of user involvement: participatory design. In this design process, users are involved all along products development, and particularly during concepts design. Participatory design would allow better access to users' needs, expectations, and tacit knowledge. The objective of this project is to study how the level of drivers' involvement in the design process impacts the usability, distraction and acceptance of trucks human-machine interfaces. After a preliminary analysis of the context of use, three instrument cluster design processes were conducted in parallel using a tactile equipment. The outcomes of these three processes, differing in level of user involvement, were evaluated and compared in a driving simulator experiment. The results do not enable to demonstrate that participatory design has a significant impact on usability, distraction and acceptance. This thesis concludes with recommendations to practitioners and research perspectives.

Keywords

Human-machine interface; user involvement; user-centered design; participatory design.

Contents

List of publications

This thesis is based on the following papers and reports, which will be referred to in the text by the following numerals:

Paper I François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2017). Automotive HMI design and participatory user involvement: review and perspectives. Ergonomics, 60(4), 541-552.

Report I François, M., Crave, P. (2015). Identify and specify MPV HMI Context of use. Volvo Group Trucks Technology. Internal report: unpublished.

Report II François, M., Crave, P. (2016). Human-factors guidelines: a review for the design of trucks HMI. Volvo Group Trucks Technology. Internal report: unpublished.

Paper II François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2016). Analogue versus digital speedometer: effects on Distraction and Usability for Truck Driving. In Morris, A., Mendoza, L. (Eds.). Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems, Loughborough, UK, June 30st - July 1st 2016 (p. 18-25). Lyon: Humanist Publications.

Paper III François, M., Crave, P., Osiurak, F., Fort, A., & Navarro, J. (2017). Digital, analogue, or redundant speedometers for truck driving: Impact on visual distraction, efficiency and usability. Applied Ergonomics, 65, 12-22.

Paper IV François, M., Fort, A., Crave, P., Osiurak, F., & Navarro, J. (2017). Gauges design on digital instrument cluster: efficiency, distraction, and satisfaction assessment for truck driving. Manuscript submitted for publication.

Paper V François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2017). Usability and acceptance of truck dashboards designed by drivers: two participatory design approaches compared to user-centered design. Manuscript submitted for publication.

Paper VI François, M., Fort, A., Osiurak, F., Crave, P., & Navarro, J. (2017). Efficiency and distraction of truck dashboards designed by drivers: two participatory design approaches compared to user-centered design. Manuscript in preparation.

Preface

A few years ago, a workshop was organized at Renault Trucks by the team in charge of defining the storage spaces in trucks. Truck drivers were invited to build their “ideal storage”. For this, they could hang boxes of different volumes in the cabin and fill them with the objects they used to bring with them into the truck.

The team in charge of defining the human-machine interfaces was inspired, and had in mind to let drivers define their interfaces to see the result. Unlike for storage, some concerns have come forward such as the safety impact. Above all, questions have emerged: will drivers know what they want? Will they be able to define easy-to-use and safe interfaces? How can we organize workshops so that they can express themselves without going through our constraints and complex software use?

We hope that this thesis will provide answers and perspectives to those who also ask themselves these questions.

This project was carried out within the Renault Trucks company (Volvo Group) in collaboration with the laboratory EMC (University Lyon II) and the laboratory LESCOT (IFSTTAR). As the Volvo Group is international, this thesis has been written in English.

Introduction

The objective of this research is to study how the level of drivers' involvement in the design process impacts the usability, distraction and acceptance of trucks human-machine interfaces (HMI). In this introduction, the object of study will first be defined (trucks human-machine interfaces, human-centered design and user involvement); followed by a brief presentation of the state of knowledge on participatory design and HMI design (and the missing areas of the literature); and then the objectives and structure of the project will be exposed. Finally, the Paper I presents a review of the existing literature on the benefits of participatory design and reveals perspectives for the design of automotive HMI.

1. What are we studying?

1.1. Trucks human-machine interfaces

Human-machine interfaces define all devices that allow communication between a technology and its user. In a truck, HMI include all parts of the truck that allow the driver to act on the vehicle (e.g. controls allow the driver to engage a function of the vehicle) and the vehicle to provide information to the driver (e.g. instrument cluster displaying information such as speed) (Fig. 1).

Figure 1: Renault Trucks human-machine interfaces (HMI) of the multi-purpose vehicles (MPV) in 2017

Trucks HMI have several specificities:

- They are mainly used while driving. To avoid safety risks, trucks interfaces should be conceived to minimize driver distraction (i.e. eyes-off-road time, hands-off-wheel duration, and cognitive load while interaction with the interface) and to increase usability (mainly to avoid errors). Marcus (2004) illustrated well this design challenge: “Imagine having to think about safety, usability, and esthetics issues for the user interface of a two-ton mobile device hurtling through space at 100 km/h. Now you get the picture” (p. 91).
- With technological advances, the information to be displayed is increasingly numerous and complex (Gkouskos, Normark, & Lundgren, 2014). To avoid drivers’ errors while interacting with a system, interfaces should be very usable. Designers should carefully define which information to present to the driver, how to display it, and specify a logic of interaction that ensures an easy, quick, and error-free access to information.
- In today’s trucks, the same HMI is used in various contexts of use. Indeed, the same HMI is designed for a range of vehicles. In this project, we focused on a specific range of trucks: multi-purpose vehicles (MPV, Fig. 2). They are vehicles between 10 and 26 tons mainly intended for the distribution of goods or light construction (e.g. delivery of equipment on construction sites). They are different from heavy-duty vehicles; often used for long haul or heavy construction. Multi-purpose vehicles are used in very various contexts of use implying different needs in term of HMI. 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. Therefore, in addition to being easy to use and not distracting in all contexts, HMI design should ensure to cover all needs of the users in the different contexts of use to provide a good acceptance.

Figure 2: Renault Trucks range of vehicles above 6,5 tons in 2017, with the segmentation between heavy-duty trucks (mainly for long haul and heavy construction) and multi-purpose vehicles (MPV). This project focused on multi-purpose vehicles.

1.2. Human-centered design

The design of trucks' human-machine interfaces (HMI) has long been based on the extent of features and technical constraints imposed by the technology. Nevertheless, the growing amounts of in-vehicle devices and road safety issues led to a shift from a techno-centric design to an anthropo-centric design. Human-centered design is an approach aiming at conceiving usable and useful products (ISO 9241-210, 2010). The human and users' needs and requirements are in the center of the development process. The goal is to improve users' comfort with the product and to counteracts potential adverse effects of its use (e.g. safety risks). Human-centered design processes are divided into different phases (Fig. 3). A first phase is an analysis, consisting in the identification and specification of the context of use and user requirements. The users and their characteristics, their goals and tasks, and the environment of the system are defined and transposed into requirements. In a second phase, concepts are designed based on the requirements. The design of these concepts relies on the outcomes of the first phase of analysis. The third phase is an assessment phase, in which it is evaluated whether the concepts of the previous phase meet user requirements. Based on the results of this phase, iteration can be made with previous phases until a desired outcome is achieved (e.g. return to the analysis phase if new requirements are discovered during the evaluation). This process can be applied to obtain feedback on initial design concepts before requirements are finalized (early in the development process, before design, verification and validation).

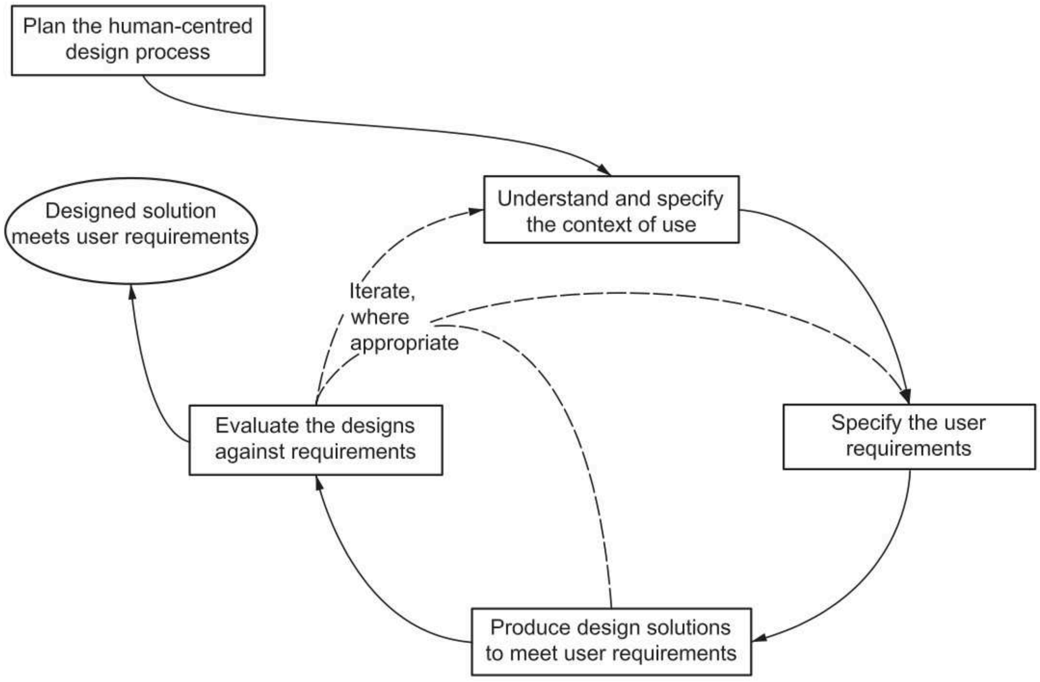


Figure 3: Human-centered design activities (ISO 9241-210, 2010)

1.3. User involvement

One of the principle of human-centered design is to actively involve users (Maguire, 2001). It is widely acknowledged that user involvement in the design process provides a valuable source of knowledge about the context of use, the tasks, users' needs and expectations, and the way they could react to a new product (Bekker & Long, 2000; Rogers, Sharp, & Preece, 2011). However, the nature and frequency of this involvement can vary among approaches.

Three levels of user involvement have been distinguished in the literature:

- The user can be considered as a source
- of relevant data. Eason (1995) characterizes this level as a "design for users", the involvement type is "informative" (Damodoran, 1996).
- The user can evaluate solutions. This level corresponds to a "consultative" involvement (Damodoran, 1996), in a "design with users" (Eason, 1995).
- The user can participate in design. This "participative" involvement (Damodoran, 1996) is implement in "design by users" (Eason, 1995).

A major aspect of user involvement is pointed out by Damodoran (1996): levels of user involvement do not have clear boundaries, but can be characterized as being somewhere on the continuum from informative, through consultative, to participative.

Human-centered approaches are manifold, e.g. ethnography (Blomberg, Giacomi, Mosher, & Swenton-Wall, 1993), lead user approach (Herstatt & Von Hippel, 1992), contextual design (Beyer & Holtzblatt, 1999), joint application design (Carmel, Whitaker, & George, 1993) and empathic design (Leonard & Rayport, 1997). However, the two major design approaches are user-centered design (UCD) and participatory design (PD) (Bekker & Long, 2000). Based on these different levels of user involvement, the two approaches can be differentiated as follows (Bekker & Long, 2000; Bratteteig & Wagner, 2016; Carroll, 1996; Kujala, 2003; Sanders, 2002; Spinuzzi, 2005):

- User-centered design (UCD) would be a design for and with users, with informative and consultative forms of involvement. Indeed, users are involved during the phases of analyses, using techniques such as surveys, interviews, or activity analysis. They are also involved during the assessment phase, where designers observe how they react to concepts and collect their feedback (usability tests). In user-centered design processes, concepts are designed by experts.
- Participatory design (PD) would correspond to a design by users, with a participative involvement. Users are involved all along the development process. They participate in the

analyses and assessment phases, but also during the concept design phase. During this phase, techniques such as storytelling, journal, brain drawing, or prototyping are used.

Nowadays, user-centered design is widely used in trucks HMI design (e.g. Engström et al., 2006; Hesse et al., 2011; Marberger, Dangelmaier, Widlroither, & Bekiaris, 2004). However, there is a trend for more and more user involvement in design (Marcus, 2004; Sanders & Stappers, 2008). Participatory design could therefore provide interesting perspectives.

2. What do we already know about it?

2.1. User-centered design benefits and limitations

Maguire (2001) summarized user-centered design benefits as follows:

- Increased productivity: users can complete tasks without requiring unnecessary time or cognitive resources;
- Reduced errors: a development centered on usability aspects enables avoiding inconsistencies, misunderstanding, or other defaults leading to errors;
- Reduced training and support: by producing more usable products, user-centered design reduces learning time and the need of support;
- Improved acceptance: as users assess concepts before market release, and conception is centered on users' needs, user-centered design product would be highly used and trusted;
- Enhanced reputation: benefits on a marketing point of view.

When designing concepts, designers take their decisions based on different information: human-factors aspects, costs, timing of projects, brand image, etc. They have a holistic point of view, considering all usages, drivers and tasks, but also considering all HMI configurations. For example, when defining an eco-coaching interface to promote fuel economy:

- Indicators should be relevant for all road environment and vehicle load;
- Information displayed should be detailed enough for an expert driver in eco-driving but easy to understand for a novice driver;
- The layout should be as good for a truck having the adaptive cruise control and for the truck without any option.

Considerations are global and not individual.

Nonetheless, some limitations can be addressed to UCD. First, the controlling approach of user-centered design is criticized (Lee, 2008). HMI concepts are created by experts and users are only consulted to evaluate them. User-centered design focuses principally on how users react to a prototype and misses what they could bring during concepts design. Second, leading user-centered design on projects with many constraints can be rather exhaustive. For example, when defining a new wiper stalk, the number of different HMI configuration is limited. In this case, all configurations could be tested in a usability test to ensure which configuration is the best. However, technological advances bring a new flexibility in HMI design. If wiper controls would be implemented in a touchscreen on the dashboard, the number of different representation, size, layout, or information to display would increase, and all configurations would be less likely to be covered in one usability test. This is a contemporary design challenge to face with the arrival of instrument clusters as screens. Third, the quality of a UCD interface is impacted in part by what designers know – or not know – about users (Weinschenk, 2011). Nevertheless, human-factors guidelines and ergonomic knowledge are extensive, but not exhaustive. Getting information on the context of use and getting feedback on users' reaction are time-consuming, and could not cover all design decisions to be made.

One solution that would answer these limits would be that users know what they need and what they process easily and efficiently. If this was the case, involving them in the design would save time and increase quality. In other words, if users know what they need and process well, they should participate in design, instead of designers spending time trying to figure out what they need and process well.

2.2. Participatory design perspectives

The main benefits of participatory design are summarized by Damodaran (2006):

- Improved product quality due to better definition of user requirements;
- Avoidance of costly features that users do not need or use;
- Better acceptance;
- Greater understanding of users;
- Increased participation in decisions making.

The rationales for a shift toward a participative involvement were stated by Carroll and Rosson (2007): a moral aspect (i.e. users have a right to be involved in decision making) and a pragmatic aspect (i.e. users' experience and knowledge can offer insights for concepts design). The moral aspect refers to the origins of participatory design. Participatory design appeared in the Scandinavian countries in the 1970s and 1980s (Ehn, 1993; Floyd, Mehl, Reisin, Schmidt, & Wolf, 1989). The implementation of computers in workspaces has generated partnerships between researchers, trade unions and workers to optimize this change (Spinuzzi, 2005). The pragmatic aspect, with potential benefits on the ergonomic quality of the interfaces, would rely on two factors. Users would have different levels of needs (i.e. explicit, observable, tacit and latent) including implicit needs that could not be expressed in talking or using a concept (Sanders, 2002). By making a concept, users would provide a direct access to these needs, leading to more useful and thus more accepted products. Users would also rely on tacit knowledge when interacting with an interface (i.e. implicit knowledge). For example, when presenting a new instrument cluster to a driver, the location of his/her first look will depend on different general and individual factors such as his/her culture (e.g. direction of reading in his language), on general cognitive processes (e.g. a blinking information in the peripheral vision will grab his/her attention), and on what he/she is expecting based on his/her past experiences and tacit knowledge. Even if general aspects can be addressed by human-factors guidelines, ergonomic knowledge, and explicit activities, the individual implicit aspects are less accessible. In a participatory design, as the user is the designer, he would use his implicit knowledge directly as resources for design. For example, during his career, a truck driver interacts with several instrument clusters from different brands. Based on his experiences, he builds a mental model of an instrument cluster, with what he wants to see and where he wants to see it. When interacting with a new instrument cluster, he will rely on this mental model. Therefore, if interfaces do not fit drivers' mental representations, they may lead to misuse, potentially hazardous situations, and rejection of the system (Carroll & Olson, 1987). As they imply high variability and interpersonal differences for HMI interaction, tacit knowledge acquired by drivers through experience and automatization is crucial as input to user requirements. Taking this knowledge into account would lead to interfaces that would be easier to use and more efficient (and therefore less distracting).

2.3. What is missing?

Based on the existing literature, the remaining shadow areas would be the following. First, there is a trend for more and more user involvement in design (Marcus, 2004; Sanders & Stappers, 2008), but there is a lack of empirical and rigorous evidence in favor of this. Indeed, even if benefits are reported for participatory design, they are not compared with the potential benefits collected with a user-centered design on the same case. Second, there are many evaluations of PD processes (Bossen, Dindler, & Iversen, 2016), but few rigorous evaluations of PD outcomes. Bratteteig and Wagner (2006) stressed an urge to move the attention from how to carry an approach to how successful outcomes are. Third, benefits are often attributed globally to PD, however there are many other ways to collect a PD outcome (Bratteteig & Wagner, 2016). The different participatory methods may differ in terms of cost, resources used, time spent, etc. Differences in outcomes should receive adequate attention to guide practitioners towards the method that corresponds to their expectations. Finally, unlike other types of interfaces where subjective criteria may prevail, efficiency and distraction of instrument clusters are critical for road safety. It is essential to measure rigorously the effects of PD on efficiency and distraction aspects. This aspect is even more topical in a perspective of dashboard personalization (Marcus, 2004).

2.4. How will this thesis advance our knowledge?

This thesis aimed at improving knowledge on the more efficient way to involve drivers to create easy to use and safe interfaces. Implementing different participatory methods on a concrete application case allows experiencing different methodologies and answering to the following questions: do drivers know what they want and what they will process well, i.e. do they have accurate meta-representations of what they could use efficiently and safely. If so, then participatory design should impact positively usability, distraction, and acceptance. Besides that, there are a variety of participatory methods that can be implemented, requiring different resources (e.g. time, cost, people). Studying the impact of the participatory method used on the quality of the concepts generated is fundamental for practitioners. Additionally, one of the objectives was to increase practitioners' knowledge for user-centered design, by providing an analysis of multi-purpose vehicles HMI context of use, reviewing, and completing existing human factors guidelines.

More precisely, this thesis addressed the following research questions:

- RQ1: How the level of driver involvement in the design process impacts the usability, distraction and acceptance of truck HMI?
- RQ2: Is the ergonomic quality of the interfaces impacted in the same way according to the participative method implemented?

2.5. Research approach

The structure of this research, and the associated papers and reports are presented in Figure 4.

This research was divided into three sub-projects, following the three steps of the human-centered approach: analysis of the context of use, concepts design, and concepts assessment. They were conducted sequentially, each sub-project using outputs from previous activities.

Paper I: State of the art

First, a preliminary state of the art was carried out before the first sub-project (Paper I). The objective of this article was to provide a comprehensive literature review of the benefits of participatory design and to report on the perspectives to meet automotive HMI challenges. This enabled to define the objectives and the structure of the project.

Sub-project 1: Analysis of the context of use

In the first sub-project, the objective was to identify and specify the context of use of trucks HMI. This includes an analysis of the vehicles and users on which this thesis focused. Indeed, the human-centered design of a HMI requires considering certain information such as the HMI configurations with which users interact, their tasks, the environment of use, and the characteristics of the users. These data were used to determine the scope of the design activity, which drivers to involve for participatory design, and served as input for the user-centered design.

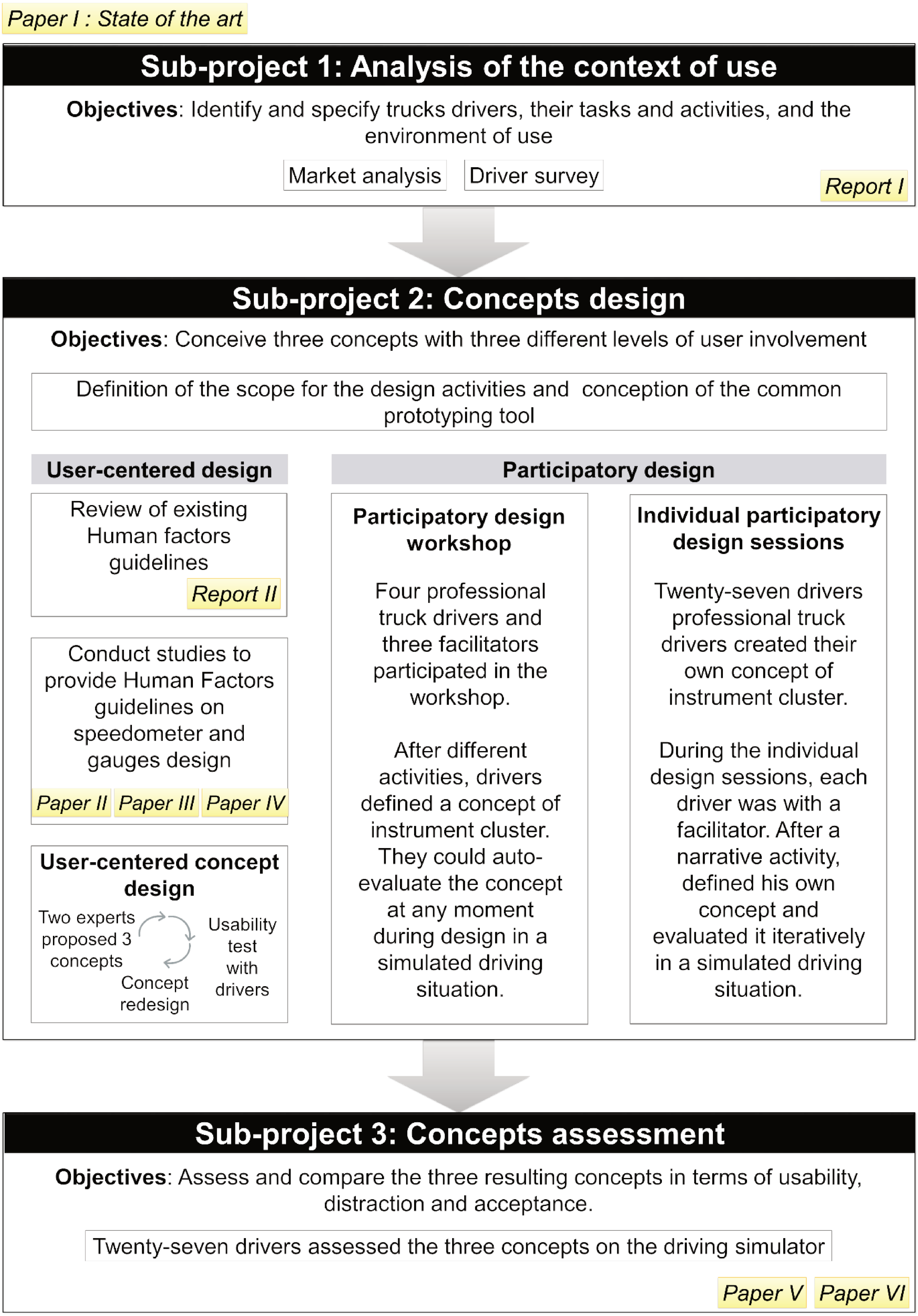
Sub-project 2: Concepts design

In a second sub-project, three instrument cluster design processes were conducted in parallel using a tactile equipment:

- A user-centered design (UCD) process was first conducted (i.e. consultative involvement). As design inputs, a preliminary review of the human-factors guidelines was carried out, as well as three experiments to complement these recommendations (on speedometers and gauges design). Drivers evaluated three concepts designed by HMI experts to reach a final concept: the UCD concept.
- A participatory design workshop (PDWS) was conducted with four professional truck drivers (i.e. participative involvement). Various activities performed during a one-day workshop led to the design of a common concept: the PDWS concept.
- Individual participatory design (PDInd) sessions were carried out with twenty-seven drivers. Each driver defined his own concept and evaluated it iteratively in a simulated driving situation. Twenty-seven individual concepts were therefore collected (PDInd concepts).

Sub-project 3: Concepts assessment

The third sub-project aimed at assessing the outcomes from the three processes conducted in the second sub-project. The twenty-seven drivers assessed the UCD concept, the PDWS concept, and their own concept. Usability, distraction and acceptance were measured on truck simulator with predefined scenarios and tasks involving the use of the interfaces.



Objectives: Identify and specify trucks drivers, their tasks and activities, and the environment of use

Objectives: Conceive three concepts with three different levels of user involvement

Definition of the scope for the design activities and conception of the common prototyping tool

Conduct studies to provide Human Factors guidelines on speedometer and gauges design

Four professional truck drivers and three facilitators participated in the workshop.

After different activities, drivers defined a concept of instrument cluster. They could auto-evaluate the concept at any moment during design in a simulated driving situation.

Twenty-seven drivers professional truck drivers created their own concept of instrument cluster.

During the individual design sessions, each driver was with a facilitator. After a narrative activity, defined his own concept and evaluated it iteratively in a simulated driving situation.

Objectives: Assess and compare the three resulting concepts in terms of usability, distraction and acceptance.

Twenty-seven drivers assessed the three concepts on the driving simulator

Figure 4: Structure of the PhD Project

Paper I

Automotive HMI design and participatory user involvement: review and perspectives

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Automotive HMI design and participatory user involvement: review and perspectives

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ABSTRACT

Automotive human–machine interface (HMI) design is facing new challenges due to the technological advances of the last decades. The design process has to be adapted in order to address human factors and road safety challenges. It is now widely accepted that user involvement in the HMI design process is valuable. However, the current form of user involvement in industry remains at the stages of concept assessment and usability tests. Moreover, the literature in other fields (e.g. information systems) promotes a broader user involvement with participatory design (i.e. the user is fully involved in the development process). This article reviews the established benefits of participatory design and reveals perspectives for automotive HMI quality improvement in a cognitive ergonomic framework.

Practitioner Summary: Automotive HMI quality determines, in part, drivers' ability to perform primary driving tasks while using in-vehicle devices. User involvement in the design process is a key point to contribute to HMI quality. This article reports the potential benefits of a broad involvement from drivers to meet automotive HMI design challenges.

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1. Introduction

For a long time, the design of automotive human–machine interfaces (HMI) was determined by technical constraints and the extent of the features made possible by the technology. Nevertheless, the limited amounts of information that can be handled by the driver and road safety issues have forced a shift in design approach. Human–machine interface design has moved from technology-centred and feature-driven approaches to human-centred design approaches (i.e. applying human factors and usability knowledge). Among human-centred approaches, user-centred design (i.e. considering the users' perspective to achieve a usable system) has become the standard for automotive HMI design. Drivers are involved during usability tests for interface assessment, and it is now widely accepted that user involvement in the HMI development process is valuable (e.g. Bekker and Long [2000]; Preece, Rogers and Sharp, 2011).

Another human-centred approach, participatory design, has had great success for more than four decades and has demonstrated clear benefits in other fields (e.g. information systems, physical ergonomics). Participatory design implies a proactive role by the user throughout the process, including concept design activities. Compared to other approaches, participatory design may allow the accessing of users' mental models and preferences, which would improve product quality and user acceptance (Spinuzzi 2005). In the HMI design field, few articles have reported on participatory design (e.g. Moraes and Padovani [1998]; Bruno and Muzzupappa [2010]; Bilal [2013]), and none of them made a cognitive ergonomic evaluation of the product designed (e.g. measures of efficiency and satisfaction).

Therefore, the question arises: How could automotive HMI design benefit from participatory design compared to user-centred design from a cognitive ergonomic perspective? The objective of this article was to provide a comprehensive literature review of the benefits of participatory design and to report on the perspectives to meet automotive HMI challenges.

In the first section, cognitive ergonomic challenges related to automotive HMI design are presented. Then, a review of participatory design benefits is provided in the second section. Lastly, participatory design benefits are linked to automotive HMI challenges to highlight potential research and application perspectives. This article

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Table 1. A framework to qualify automotive HMI cognitive ergonomic quality.

HMI quality criterion	Attribute	Description
Usability (according to Nielsen 1994)	Learnability	The HMI enables the user to learn how to use it at first encounter
	Efficiency	The HMI enables the user to complete the correct task without requiring unnecessary resources
	Memorability	The HMI enables the user to remember how to use it after a period of not using it
	Errors	The use of the HMI does not imply errors and enables an easy recovery from an error
	Satisfaction	The use of the HMI is pleasant
Distraction (according to Chapon, Gabaude, and Fort 2006)	Physical	The HMI optimises required movement to perform a task
	Cognitive	The HMI reduces required cognitive workload to perform a task
Driver acceptance (according to Davis, Bagozzi, and Warshaw 1989)	Perceived usefulness	The degree to which a person believes that using the HMI is useful and enhances his performance
	Perceived ease of use	The degree to which a person believes that using the HMI is free from effort
	Attitude	User's feelings about performing the task with the HMI

concludes with a discussion on the participatory design approach.

2. Automotive HMI design

The quality of the automotive HMI determines, in part, the driver's ability to perform the primary driving task while using in-vehicle devices. Various internal and external factors (Leplat 1981) can influence interaction quality. Internal factors are driver characteristics (e.g. experience level, motivation, age, emotional status and time pressure). External factors include context characteristics (e.g. level of emergency, task consequences and lighting conditions) and the characteristics of the interface itself (e.g. ease of use, menus, modality used, colours and voice recognition). Human–machine interface designers have a limited impact on driver and context factors. However, by specifying interface characteristics, HMI designers directly impact the way the user interacts with a device and performs the primary task. Cognitive ergonomic criteria are used by HMI designers as design principles as well as assessment factors to generate interfaces compatible with human capabilities and limitations. In this article, we will focus on three fundamental criteria for automotive HMI: usability, distraction and acceptance.

These three criteria cover the main measures existing in the literature to define the quality of an interface. Usability is the most used criterion for interface evaluations, but driving safety and user acceptance can have critical implications for automotive HMI due to the specific context of use. The theoretical question of interaction and weight between these three criteria is not addressed in this article. More detailed and specific models on the ergonomic quality of automotive HMI exist in the literature (e.g. Harvey et al. 2011). In this article, the objective is to adopt a holistic and practical framework in order to examine automotive HMI design challenges and meet practitioners' concerns. The proposed framework based on the three criteria (i.e. usability, distraction and acceptance) is presented in Table 1. In the following parts, each criterion is defined with its scope and the associated design challenges.

2.1. Usability

Nielsen (2012) defined usability as 'a quality attribute that assesses how easy user interfaces are to use'. It is the leading criterion in the cognitive ergonomic literature to define HMI quality. Many models of usability were proposed; Nielsen (1994) summarised with the following five constructs: learnability, efficiency, memorability, errors and satisfaction (see definition in Table 1). Besides those constructs, many subcriteria of usability have been proposed that are not really consistent across standards. Baber (2005) highlighted this diversity by reviewing 34 different factors of usability. The International Organization for Standardization (1998) considered three aspects: effectiveness (i.e. accuracy and completeness to complete a task), efficiency (i.e. resources expended to complete a task) and satisfaction (i.e. comfort and pleasure of usage). Constantine and Lockwood (1999) defined usability as a combination of learnability, system reliability, efficiency, memorability and user satisfaction. Preece et al. (2011) associated learnability with flexibility, throughput and attitude. Shackel (1986) identified four usability criteria: learnability, flexibility, effectiveness and user attitude. Stanton and Baber (1992) added perceived usefulness, task match, task characteristics and user criteria. Shneiderman (1992) proposed five attributes: time to learn, speed performance, rate of errors, retention over time and subjective satisfaction. Nevertheless, the different terms often overlap the same characteristics. The model of Nielsen (1994) has the advantage of presenting a global and representative view of the main theories. The learnability criterion was also present in the models of Constantine and Lockwood (1999), Preece et al. (2011), and Shackel (1986) and matches the criterion of time to learn of Shneiderman (1992). Efficiency encompasses the notions of effectiveness (Shackel 1986; International Organization for Standardization 1998), efficiency (International Organization for Standardization 1998; Constantine and Lockwood 1999), throughput (Preece et al. 2011) and speed performance (Shneiderman 1992). The memorability construct has already been presented by Constantine and Lockwood (1999) and matches the concept of retention over time of Shneiderman (1992). The errors' criterion embraces the following criteria: system reliability (Constantine and Lockwood 1999), flexibility (Shackel 1986; Preece et al. 2011) and rate of errors (Shneiderman 1992). Finally, satisfaction was already present in definition of usability (International Organization for Standardization 1998; Constantine and Lockwood 1999) and matches the constructs of attitude (Shackel 1986; Preece et al. 2011) and subjective satisfaction (Shneiderman 1992).

During automotive HMI design, one way to incorporate usability is to follow design principles, i.e. HMI guidelines (Stevens et al. 2002; JAMA 2004; Commission of the European Communities 2005; Campbell et al. 2007) or usability heuristics (Bastien and Scapin 1992; Nielsen 1994). Likewise, tests can be performed after concept definition to assess HMI usability. Nevertheless, some criteria are easier to assess than others. For example, errors can be measured in terms of type, rate and ease of recovery, but user satisfaction could comprise any number of different subattributes. Moreover, memorability could be more significant for infrequently used vehicle functions (e.g. fog lights) than for those which are used frequently (e.g. indicators).

2.2. Distraction

Distraction is defined in the literature as a diversion of attention from the driving task to a concurrent activity (Pettitt, Burnett, and Stevens 2005). Distraction can be related or not to driving and due to an event, object or person inside or outside the vehicle (Chapon, Gabaude, and Fort 2006). The interaction with automotive HMI can result in distraction related to driving (e.g. following a map on a GPS) or in not related to driving (e.g. changing radio volume). In both cases, the interaction with the HMI could imply physical distraction (e.g. at least one hand off the steering wheel and eyes off the road) and/or cognitive distraction (i.e. cognitive workload needed to perform a task; Chapon, Gabaude, and Fort 2006). Distraction can significantly impair the driver's visual search patterns, reaction times, decision-making and/or driving performance (e.g. position on the road; Young, Regan, and Hammer 2007). Divided attention in itself leads to an increased workload; mental workload management while interacting with in-vehicle devices is therefore crucial to keep resources available for the primary driving task (Young et al. 2015).

The distraction criterion is central in the automotive HMI domain and is, for that reason, treated separately here from usability, even though this concept is clearly linked with efficiency. Indeed, in-vehicle HMI is used under a specific context of use. The importance of the dual task interference (Harvey et al. 2011) and its impact on driver distraction distinguish automotive HMI from other user interfaces (Marcus 2004).

During design, many interface characteristics can be considered to reduce distraction. For example, Reimer et al. (2014) stressed that the typeface design in an automotive user interface impacts on task completion time and visual demand while driving (e.g. a difference of more than 10% of total glance time was found between two typefaces). However, for HMI designers, anticipating sources of distraction during concept design is quite complex. The distraction criterion is most often addressed through assessment with measures such as driving performance during interaction (Young et al. 2007), gaze away from road (e.g. total eyes off-road time, maximum glance duration; Larsson and Niemand 2015), cognitive workload (Stanton et al. 2013), situation awareness (Ma and Kaber 2007) and reaction times (Navarro, Mars, and Hoc 2007). Moreover, a guideline has been created to assess driver distraction (NHTSA 2012) with visual–manual distraction metrics and acceptance thresholds (e.g. devices should be designed so that drivers can interact without looking away from the road for more than 2 s).

2.3. Driver acceptance

Driver acceptance is defined by Adell (2010, 477) as 'the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving'. Driver acceptance covers user attitudes, their subjective experiences and their willingness to use technology for the task for which it was intended. Acceptance contributes widely to automotive technology adoption (i.e. the use of a device as part of a driver's everyday life; Najm et al. 2006). Following the rapid development of technology, the concept of acceptance and its relation to usage behaviour has become a significant research question. A number of different models have put emphasis on different aspects of user acceptance. Among the many variables that may influence acceptance or rejection of a technology, the technology acceptance model (TAM; Davis, Bagozzi, and Warshaw 1989) – based on the theory of reasoned action (Fishbein and Ajzen 1975) – suggests that perceived usefulness and perceived ease of use impact on user attitudes towards using, determining the behavioural intention to use. More recently, Venkatesh et al. (2003) proposed the unified theory of acceptance and use of technology. This model states that usage behaviour is influenced by intention to use and facilitating conditions. The intention to use is in turn impacted by performance expectancy, effort expectancy and social influence. Besides those factors, Nielsen (1994) has stressed the importance of utility when describing practical acceptance. Indeed, a system can be usable but not necessarily useful. Van Der Laan, Heino, and De Waard (1997) confirmed this point by identifying usefulness and satisfaction as the two dimensions of acceptance. Willingness to use is also dependent on driver satisfaction, and some subjective criteria are suggested such as aesthetics, emotional appeal, pleasure, fun, coolness and attractiveness (Preece, Rogers, and Sharp 2011; Baber 2005).

Although subjective attributes are recognised as playing a great role in user acceptance, they are more difficult to translate into specifications during HMI concept design. Furthermore, the concept of acceptance relates to the user's attitude towards a technology, and the HMI only partially contributes to this (e.g. Brown et al. [2015]). Driver acceptance is therefore often addressed during concept assessment through questionnaires and subjective reports (e.g. Van Der Laan, Heino, and De Waard [1997]).

3. User involvement and design processes

During product development, even if designers are close to users and know product usages, their perceptions and reflections could be modulated by their knowledge. Nielsen (2008) reported that designers know too much about the product, are too skilled in using computers or tools in general and 'care too much about their own baby'. The ISO 13407 guideline (1999) thus recommends active user involvement to create products compatible with users, tasks and environment requirements. The human-centred approach aims to take into account the context of use and human factors. According to ISO 9241–210 (2006), the human-centred design process splits into three stages through an iterative process: (1) analysis (understanding context of use and specifying user requirements), (2) concept design and (3) concept assessment. Human-centred design includes different design methodologies according to their level of user involvement throughout the process. Eason (1995) distinguished three levels of user involvement for product development: a design for users, a design with users and a design by users. Damodaran (1996) took up those levels by characterising user involvement as being somewhere on the continuum from informative, through consultative, to participative. The correspondence between those three levels of user involvement and the stages of the human-centred design process is presented in Figure 1.

3.1. User-centred design: a design for and with users

Human-centred approaches are manifold, e.g. ethnography (Blomberg et al. 1993), the lead user approach (Herstatt and Hippel 1992), contextual design (Beyer and Holtzblatt 1999), joint application design (Carmel, Whitaker, and George 1993) and empathic design (Leonard and Rayport 1997). Among human-centred approaches, the user-centred design process has been widely and predominantly used for about 30 years. The main goal is to develop a product while keeping the user in mind and

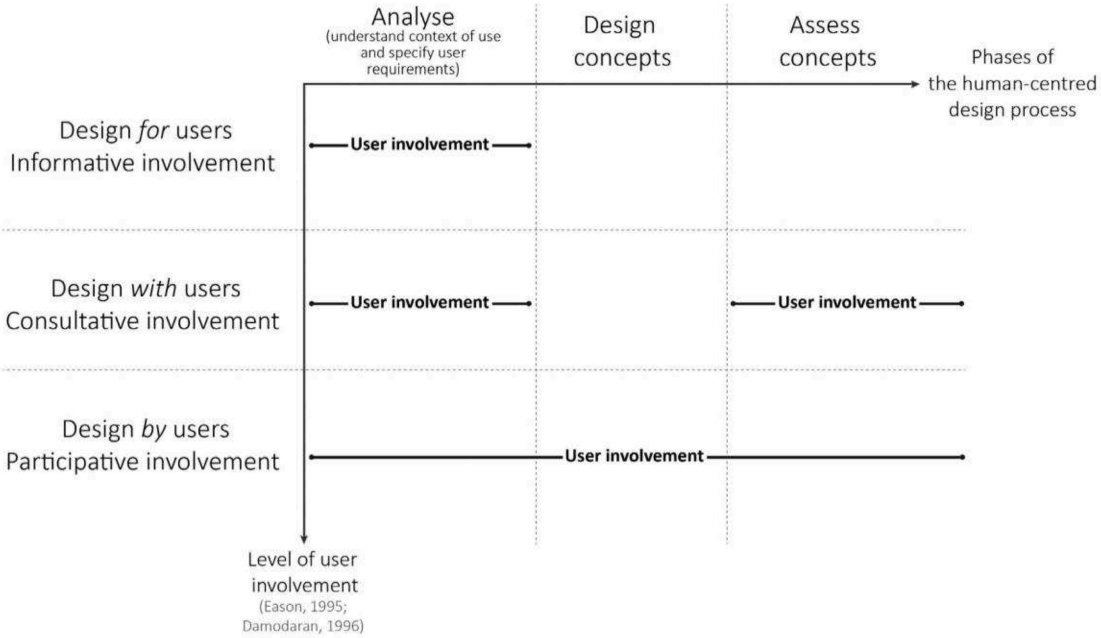

Figure 1. A correspondence between the different levels of user involvement and the phases of the human-centred design process.
Note: Figure adapted from Kaulio (1998).

promote usability by detecting and avoiding potential interaction issues before product implementation (Gould and Lewis 1985; Karat 1997). User-centred design plays a significant role in research and practice to consider users' needs and expectations, focus on interaction and improve communication between designers and users.

User involvement in user-centred design is informative and/or consultative (Bekker and Long 2000). With informative involvement, users are considered as a source of information for the analysis stage, but the design team ensures the concept design and assessment. Information on users is collected using different tools such as surveys (Preece et al. 1994), field studies (Preece et al. 1994), diary keeping (Poulson, Ashby, and Richardson 1996), task analysis (Kirwan and Ainsworth 1992), user requirement interviews (Macaulay 1996), focus groups (Caplan 1990), personas (Olsen 2004) and scenario of use (Nielsen 1990).

With consultative involvement, users provide information during the analysis stage but also take part in the assessment phase. They are requested to give their feedback on concepts designed by the design team (e.g. with usability tests). Dumas and Redish (1999) summarised the main benefits of usability testing: to improve the product's usability, involve real users, give users real tasks to accomplish, enable designers to observe and record users' actions and enable designers to make changes accordingly.

Notwithstanding, some limitations can be reported for user-centred design. The principal criticism is that designers have a controlling approach (Lee 2008). In fact, concepts are created by engineers, and users are only consulted to evaluate them. The implementation of user-centred design in practice often implies an assessment with a limited set of features covered, during a limited time, and, often, with a small number of participants (Abras, Maloney-Krichmar, and Preece 2004). Moreover, user-centred design focuses principally on how the user reacts to a prototype and fails to capture what they could bring to the concept design.

3.2. Participatory design: from a design for users to a design by users

Another major human-centred approach, called participatory design (or collaborative design), implies participative user involvement. With participative involvement, users contribute directly and proactively to the concept design phase (Sanders 2002). The user's role is not just confirmatory but continuous from the analysis, throughout the concept design, to the assessment stages. Although user-centred design and participatory design are very close, the active role of the user throughout the process, including concept design activities, is a major difference between the two approaches (Carroll 1996; Bekker and Long 2000; Sanders 2002; Kujala 2003).

Participatory design started in the Scandinavian countries in the 1970s for sociopolitical reasons (Floyd et al. 1989; Ehn 1992). Since that time, participatory design process has evolved away from politics and has turned into a point of interest for research. Design researchers and company designers have conducted participatory studies in many fields (e.g. interaction systems, management, services development, computer-supported cooperative work and physical ergonomics).

Several ideas support this shift towards a broader involvement of users. First, Carroll and Rosson (2007) stated the 'moral' aspect of participatory design, i.e. the fact that the user has a right to be involved in decision-making. Second, the 'pragmatic' aspect of participatory design relies on the fact that users' experience and knowledge can offer insights on concepts design (Carroll and Rosson 2007). Users are considered to be subject-matter experts who use the product in their everyday lives and have something to offer if designers offer them the right tools to express themselves (Sanders 2002). Third, a goal of participatory design is to go beyond the user's explicit consultation in order to elicit the user's tacit knowledge (Spinuzzi 2005). Tacit knowledge is the implicit knowledge that users hold about various aspects of an activity, including the way they interact with the product and perform the activity. According to Sanders (2002), the transfer of users' tacit knowledge to a concept is made possible by the fact that the user is in a 'making' situation, with the help of adapted tools. This would offer an access to their implicit skills and experiences that would be inaccessible by watching them or listening to what they say (Sanders 2002). Spinuzzi (2005) suggested that this meeting between users' tacit knowledge and researchers' more abstract analytical knowledge is the key point that leads participatory design to more successful products.

The link between user involvement and system success represents a significant body of the information systems literature since the late 1970s (Ives and Olsson 1981; Cavaye 1995; Hwang and Thorn 1999; Kujala 2003; He and King 2008; Bachore and Zhou 2009). Nevertheless, as mentioned previously, levels of user involvement are on a continuum from informative to participative (Damodaran 1996). Therefore, it is sometimes difficult to distinguish clearly the boundary between consultative and participative involvement. Moreover, Damodaran (1996, 363) reported that 'the term "user involvement" is sometimes used as a synonym for participatory design'. To present relevant findings reporting benefits of participative involvement, this review focuses on articles reporting early user involvement, user participation in concept design activities and studies aiming to be participatory design.

The main benefits of user involvement are summarised in five key points by: (1) improved product quality due to better definition of user requirements, (2) avoidance of costly features that users do not need or use, (3) better acceptance, (4) greater understanding of users and (5) increased participation in decision-making. First, the improvement of product quality is also reviewed by Bachore and Zhou (2009). Kujala (2003) reported positive the effects of user involvement on system success. Furthermore, Baroudi, Olson, and Ives (1986) suggested that user involvement has some positive effects on product usage. On participatory design studies, Clement and Van den Besselaar (1993) described the well-functioning nature of the products designed from the user perspective and their endurance over time. The improvement of the user requirements' definition is also reviewed by Kujala (2003) and Bachore and Zhou (2009). Nielsen (1994) mentioned the time wasted on certain projects arguing about what users might want or like. Participatory design allows the direct delivery of users' needs and expectations. Nielsen (1994, 88) also stated that users can bring new questions or ideas that the development team have 'not even dreamed of asking'. Second, concerning economic considerations, Karat (1997) suggested that early identification of problems can reduce time and avoid costs related to late changes. Chatzoglou and Macaulay (1996) supported this idea by arguing that early user involvement can lead to a decreased number of iterations during the design process to fulfil requirements. Third, user acceptance benefits due to user involvement are also reported by Bachore and Zhou (2009) and Kujala (2003). In one of the first participatory design projects, called UTOPIA (1981), results showed better communication between designers and users and increased user acceptance. Other subjective advantages are reported such as increased trust and user satisfaction (Weng et al. 2007), self-confidence (Clement and Van den Besselaar 1993) and personal relevance (Kujala 2003). Fourth, greater understanding of the user mainly relies on the elicitation of tacit knowledge and on a mutual understanding between designers and participants (Weng et al. 2007). Finally, the increased participation of users in decision-making can result in organisational impacts (Bachore and Zhou 2009).

In parallel to this work in information systems, physical ergonomic researchers conducted participatory studies (McNeese et al. 1995; Nagamachi 1995; Vink et al. 1995; Dixon and Theberge 2011; Morag and Luria 2013; Xie et al. 2015). Improvements are reported in terms of a reduction in physical stress, health problems and development time (Loisel et al. 2001; Sundin, Christmansson, and Larsson 2004; van Eerd et al. 2010; Gyi, Sang, and Haslam 2013). Other authors added that participative approaches could encourage sustainability (Martin, Legg, and Brown 2013; Ryan and Wilson 2013).

4. From consultative to participative user involvement: perspectives for automotive HMI design

As mentioned earlier, some limitations can be addressed to user-centred design and usability testing, it is therefore important to explore alternative development possibilities. Based on the benefits reported, participatory design could be beneficial for automotive HMI design. First, economic benefits could be expected due to the early involvement of users and the reduction in iterations needed. Moreover, the potential avoidance of costly features (Damodaran 1996) would be particularly interesting for companies wishing to develop cost-efficient HMI. For example, for a new gauge design; with a user-centred design process, the different concepts of gauges presented necessarily restrict drivers' alternatives, whereas with a participatory design process, drivers are completely free to choose another concept (e.g. only alerts indicating malfunctions). Second, a better understanding of drivers' needs could lead to a better match with market expectations. Drivers are experts, especially in the automotive field, and participatory design could allow designers to access their insights and innovative ideas. Third, increased participation in decision-making could be a beneficial from a marketing and brand image perspective. Furthermore, participatory design studies report an impact on product quality and user acceptance. These benefits might be translated for automotive HMI by an improvement in their cognitive ergonomic quality (improved usability, improved acceptance and reduced distraction).

4.1. Participative user involvement to increase HMI usability

While interacting with an interface, drivers engage working memory resources. Sweller (1988) suggested that an effective material improves and facilitates learning by directing cognitive resources to acquisition of mental models. Mental models are defined as 'a rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works, and why it works that way' (Carroll and Olson 1988, 51). In long-term memory, mental models are composed of organised elements, and it allows retrieval of subelements of information as a single element (Kalyuga, Chandler, and Sweller 1999). For example, for an automotive interface such as a climate control panel, the driver develops mental a model of the way to interact with each button and associates this with the effects on interior temperature. This model will serve as reference path for the driver to interpret and predict his future interactions (Loup-Escande, Burkhardt, and Richir 2013). Mental models are dynamic, contribute to user expertise and are part of tacit knowledge. When a mental model is acquired, interaction is automated, and the number of cognitive resources needed to perform this interaction is reduced. For example, if a map is presented on a GPS, drivers' spatial representations based on their previous interactions with a map have to be considered. If the drivers' preferred orientation of the map is met, visual search and information processing efficiency will increase. The fact that part of the user's knowledge has become tacit through automation represents one of the difficulties of involving users and understanding their requirements (Sanders 2002).

For automotive HMI design, it would be a great advantage to have access to those implicit constructs. With a user-centred design process, tacit knowledge is addressed by evaluating the degree of match between the designers' conceptual model of the interface and the users' mental models during usability tests (Norman 1993; Nielsen 2010). The focus is primarily on what users do and use and on what people say and think (Sanders 2002). With a participatory design, drivers are making concepts. This allows the consideration of skills and past experiences as resources in the design process, which is not possible by just listening or watching (Sanders 2002). Prototyping concepts with 'make tools' – so-called by Sanders (2002) – give an access to different levels of driver's needs (i.e. explicit, tacit, latent) (Loup-Escande, Burkhardt, and Richir 2013). The projective dimension could encourage idea generation, and the visual dimension could help to reveal latent needs through a possible bottom-up effect. The ideas generated would be experience based rather than only object based. Drivers' mental models 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.

4.2. Participative user involvement to decrease HMI distraction

According to the National Highway Traffic Safety Administration (NHTSA 2012), 16% of all road accidents are associated with a lack of driver's attention. Research syntheses conclude that priority should be given to minimising visual–manual interaction (NHTSA 2012). A single off-road glance (or eye closure) overlapping with a time critical event can lead to safety issues (Victor and Dozza 2011). A major part of the distraction associated with interacting with in-vehicle interfaces interaction also arises. The degree to which drivers' attention is diverted away from the primary driving task while using an in-vehicle HMI is determined in part by the design and operation of the device. For example, too much information presented through the wrong layout or information that is difficult to understand can increase workload and cause hazardous situations.

To minimise interference with driving, a consultative involvement relies on HMI guidelines and measures of distraction. The key recent NHTSA distraction guideline (NHTSA 2012) contains design recommendations and acceptance thresholds with the aim of minimising visual–manual distraction. Those measures are necessary even if a participatory design approach is applied. However, as mentioned above, user involvement during concept design could increase HMI usability and this could imply a decrease in distraction during HMI use. Indeed, a consideration of the information that the driver needs and the preferred layout associated could favour a low-clutter design resulting in increased visual search efficiency. Moreover, a better match with drivers' existing mental models could automate interaction and decrease the cognitive resources required to perform a task. By improving usability, a participative involvement in the design process could consequently decrease HMI distraction and lead to better compatibility with the driving task. The impact of participatory design on distraction would thus not be direct, but the result of a usability improvement.

4.3. Participative user involvement to increase HMI acceptance

Human–machine interface acceptance is crucial because accepted devices are more likely to be used by drivers. For example, a driver assistance system can be disabled if its HMI is annoying. Van Der Laan et al. stressed this point by stating that 'it is unproductive to invest effort in designing and building an intelligent co-driver if the system is never switched on, or even disabled' (1997, 1).

Since acceptance is individual, it can only be based on each driver's attitudes, expectations, experiences and subjective evaluation (Schade and Baum 2007). User acceptance is also affected by the degree of match between the user's initial mental model of the system and its current use (Beggiato and Krems 2013). If the interfaces do not fit the drivers' mental models and expectations, they may lead to misuse, potentially hazardous situations and rejection of the system (Maltz and Shinar 2007). Increased usability should thus improve driver acceptance. Likewise, new challenges for HMI designers are more linked to commercial aspects such as joy, aesthetics, HMI appeal or pleasure of use (Solman 2002). With consultative involvement, those subjective aspects are addressed with questionnaires during the HMI assessment. Participatory design benefits (i.e. satisfaction, product success, personal relevance, perceived ownership and intention to use) are directly linked to user acceptance (Clement and Van den Besselaar 1993; Kujala 2003; Weng et al. 2007). Drivers' participative involvement in concept design could lead to a prior consideration of those subjective aspects and have a direct influence on drivers' willingness to use and subjective experience.

5. Limitations inherent in a participative user involvement

The participative user involvement embraced by participatory design seems a promising alternative to user-centred design and could enrich the debate for HMI researchers and practitioners. Nevertheless, some limitations have to be addressed to ensure a global view. Three main limitations are identified from the literature.

First, a lack of formalised methodology has been described by many authors. a broad range of practices is deployed (Haines et al. 2002; Spinuzzi 2005; Pilemalm and Timpka 2008). To overcome this limitation, Spinuzzi (2005) stated a clear methodology for participatory design. Moreover, another reproach is that the level of involvement during participative projects is often only assessed by surveys (Ives and Olsson 1981). Notwithstanding, some articles responded to those limitations: the definition of user involvement has been clarified (Barki and Hartwick 1989) and measures to qualify user involvement have been proposed (Barki and Hartwick 1989; Torkzadeh and Doll 1994).

Second, the benefits reviewed have been contested in terms of validity. The main criticisms concern the lack of rigour with standardised, reliable and validated measures that could facilitate comparison of studies on system success, system use and user satisfaction (Ives and Olsson 1981; Cavaye 1995). Moreover, the main reviews report a qualitative evaluation of the participatory project process and lack significant objective measures on the outcome quality. Clement and Van den Besselaar (1993) added that there is little data on the long-term effects of this type of approach. Furthermore, Hawk and Dos Santos (1991) called into question the economic benefits by pointing out that user involvement is costly in terms of time and effort, and this might be even truer for participatory design (designers' training in this process, expensive prototypes). More recently, Spinuzzi (2005) proposed three criteria to assess the participatory design process involving industrial workers: quality of life for workers (i.e. improving workers' quality of life both in terms of organisational empowerment and ease of performing their given task), collaborative development (i.e. representative users or average users have to be fully involved, with a determination of a common language and common aims) and iterative process (i.e. continual participation of workers during several stages ensuring a sustained reflection). To transfer this idea to an HMI participatory design process, the criteria would be: improvement of quality (i.e. the result of the participatory design study should make interaction easier for users), collaborative development (i.e. users' concerns have to be addressed in the resulting HMI concepts and must include verification and regular group interaction) and iterative process (i.e. involvement of users repeatedly and co-development at different stages, and ensuring the appearance of the HMI concept prototype does not turn participants' attention to minor details, to ensure sustained reflection).

Last but not least, the ability of users to add value in the concept design phase will be discussed. Indeed, drivers are not HMI professional designers and could experience difficulties in considering all aspects and requirements (industrial engineering, cognitive ergonomics, technical possibilities, project-lead times, brand image, etc.). Drivers could tend to focus on a single interaction element and not adopt a holistic vision. Moreover, Scariot, Heemann, and Padovani (2012) highlighted the potential for social desirability bias, i.e. users tend to direct answers to what they believe the researcher wants to hear or what is more socially accepted. Therefore, drivers could have difficulty identifying what they want until they see it. Henry Ford's famous quote reflects this point: 'If I had asked people what they wanted, they would have said faster horses' (cited in Chandler and Van Slee [2013]). Those issues emphasise the need to have a close collaboration with HMI designers, suitable interactive prototyping tools and a rigorous methodology.

Obviously, the perspectives proposed in this article for automotive HMI design are not applicable for all types of projects. The form of user involvement to adopt depends on the available features, the number of usability risks, the gap between designers and users and the level of tacit knowledge involved in the interaction. The conception of an entire dashboard can take several years for HMI designers. The design process is therefore very important to ensure the right direction and avoid costs associated with a step backwards. Determining the moment, the type and the level of driver involvement are important aspects that should receive adequate research attention.

6. Conclusion

This review presents current automotive HMI design challenges and requirements in terms of HMI quality (i.e. usability, distraction and acceptance). The benefits of participatory design have been reviewed and linked to HMI cognitive ergonomic preoccupations. In addition to economic and marketing opportunities, two key aspects have been pointed out. First, accessing drivers' tacit knowledge through active involvement during concept design could lead to an optimisation of HMI in terms of usability and minimise distraction. Second, the consideration of drivers' mental models and preferences from the concept design stage may also improve drivers' HMI acceptance.

However, it would be important to report participatory design benefits from a relative point of view. Indeed, the lack of comparative studies between the different levels of user involvement does not allow gauging the gap in terms of quality of outcomes. Further challenges could be to compare consultative and participative involvement with rigorous methodologies and measurements on the same automotive HMI design case.

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References

Abras, C., D. Maloney-Krichmar, and J. Preece. 2004. "User-Centered Design." *Bainbridge, W. Encyclopedia of Human-computer Interaction. Thousand Oaks: Sage Publications* 37 (4): 445–456.

Adell, E. 2010. "Acceptance of Driver Support Systems." *Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems*, Berlin, Germany.

Baber, C. 2005. "Evaluation in Human-computer Interaction." In *Evaluation of Human Work*, edited by J. R. Wilson and N. Corlett, 357–387. London: Taylor & Francis.

Bachore, Z., and L. Zhou. 2009. "A Critical Review of the Role of User Participation in IS Success." *Proceedings of the Fifteenth Americas Conference on Information Systems*, San Francisco, August 6–9.

Barki, H., and J. Hartwick. 1989. "Rethinking the Concept of User Involvement." *MIS Quarterly* 13 (1): 53–63.

Baroudi, J. J., M. H. Olson, and B. Ives. 1986. "An Empirical Study of the Impact of User Involvement on System Usage and Information Satisfaction." *Communications of the ACM* 29 (3): 232–238.

Bastien, J. M. C., and D. L. Scapin. 1992. "A Validation of Ergonomic Criteria for the Evaluation of Human-Computer Interfaces." *International Journal of Human-Computer Interaction* 4 (2): 183–196.

Beggiato, M., and J. F. Krems. 2013. "The Evolution of Mental Model, Trust and Acceptance of Adaptive Cruise Control in Relation to Initial Information." *Transportation Research Part F: Traffic Psychology and Behaviour* 18: 47–57.

Bekker, M., and J. Long. 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: Proceedings of HCI 2000*, 135–147. Springer.

Beyer, H., and K. Holtzblatt. 1999. "Contextual Design." *Interactions* 6 (1): 32–42.

Bilal, D. 2013. "Children Design Their Interfaces for Web Search Engines: A Participatory Approach." *Proceedings of the Canadian Association for Information Science* 204–214, Toronto, May 30–June 1.

Blomberg, J., J. Giacomi, A. Mosher, and P. Swenton-Wall. 1993. "Ethnographic Field Methods and Their Relation to Design." In *Participatory Design: Principles and Practices*, edited by D. Schuler and A. Namioka, 123–155. Hillsdale: Lawrence Erlbaum Associates.

Brown, M., R. Houghton, S. Sharples, and J. Morley. 2015. "The Attribution of Success When Using Navigation Aids." *Ergonomics* 58 (3): 426–433.

Bruno, F., and M. Muzzupappa. 2010. "Product Interface Design: A Participatory Approach Based on Virtual Reality." *International Journal of Human-Computer Studies* 68 (5): 254–269.

Campbell, J. L., C. M. Richard, J. L. Brown, and M. McCallum. 2007. "Crash Warning System Interfaces: Human Factors Insight and Lessons Learned." *US Department of Transportation, National Highway Traffic Safety Administration*, No. HS-810 697.

Caplan, S. 1990. "Using Focus Group Methodology for Ergonomic Design." *Ergonomics* 33 (5): 527–533.

Carmel, E., R. D. Whitaker, and J. F. George. 1993. "PD and Joint Application Design: A Transatlantic Comparison." *Communications of the ACM* 36 (6): 40–48.

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., and J. R. Olson. 1988. "Mental Models in Human-Computer Interaction: Research Issues about What the User of Software Knows." In *The Handbook of Human-Computer Interaction*, edited by M. Helander, 45–65. Amsterdam: North Holland.

Carroll, J. M., and M. B. Rosson. 2007. "Participatory Design in Community Informatics." *Design Studies* 28 (3): 243–261.

Cavaye, A. L. M. 1995. "User Participation in System Development Revisited." *Information & Management* 28 (5): 311–323.

Chandler, C., and A. Van Slee. 2013. *Adventures in Experience Design*. Berkeley, CA: New Riders.

Chapon, A., C. Gabaude, and A. Fort. 2006. *Défauts d'attention et conduite automobile: état de l'art et nouvelles orientations pour la recherche dans les transports* [Attention defaults and driving: State of the art and new directions for research in transport]. Paris: Synthèse INRETS.

Chatzoglou, P. D., and L. A. Macaulay. 1996. "Requirements Capture and Analysis: A Survey of Current Practice." *Requirements Engineering* 1 (2): 75–87.

Clement, A., and P. Van den Besselaar. 1993. "A Retrospective Look at PD Projects." *Communications of the ACM* 36 (6): 29–37.

Commission of the European Communities. 2005. *European Statement of Principles on the Design of Human Machine Interaction (ESoP 2005)*. Brussels: Commission of the European Communities.

Constantine, L. L., and L. A. D. Lockwood. 1999. *Software for Use: A Practical Guide to the Models and Methods of Usage-Centered Design*. Boston, MA: Addison-Wesley.

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., R. P. Bagozzi, and P. R. Warshaw. 1989. “User Acceptance of Computer Technology: A Comparison of Two Theoretical Models.” *Management Science* 35: 982–1003.

Dixon, S. M., and N. Theberge. 2011. “Contextual Factors Affecting Task Distribution in Two Participatory Ergonomic Interventions: A Qualitative Study.” *Ergonomics* 54 (11): 1005–1016.

Dumas, J. S., and J. C. Redish. 1999. *A Practical Guide to Usability Testing*. Portland OR: Intellect Books.

Eason, K. D. 1995. “User-Centred Design: For Users or by Users?” *Ergonomics* 38 (8): 1667–1673.

van Eerd, D., D. Cole, E. Irvin, Q. Mahood, K. Keown, N. Theberge, J. Village, M. St Vincent, and K. Cullen. 2010. “Process and Implementation of Participatory Ergonomic Interventions: A Systematic Review.” *Ergonomics* 53 (10): 1153–1166.

Ehn, P. 1992. “Scandinavian Design: On Participation and Skill.” In *Usability: Turning Technologies into Tools*, edited by J.S. Brown and P. Duguid, 96–132. New York: Oxford University Press.

Fishbein, M., and I. Ajzen. 1975. *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research*. Boston, MA: Addison-Wesley.

Floyd, C., W.-M. Mehl, F.-M. Resin, G. Schmidt, and G. Wolf. 1989. “Out of Scandinavia: Alternative Approaches to Software Design and System Development.” *Human-Computer Interaction* 4 (4): 253–350.

Gould, J. D., and C. Lewis. 1985. “Designing for Usability: Key Principles and What Designers Think.” *Communications of the ACM* 28 (3): 300–311.

Gyi, D., K. Sang, and C. Haslam. 2013. “Participatory Ergonomics: Co-developing Interventions to Reduce the Risk of Musculoskeletal Symptoms in Business Drivers.” *Ergonomics* 56 (1): 45–58.

Haines, H., J. R. Wilson, P. Vink, and E. Koningsveld. 2002. “Validating a Framework for Participatory Ergonomics (the PEF).” *Ergonomics* 45 (4): 309–327.

Harvey, C., N. A. Stanton, C. A. Pickering, M. McDonald, and P. Zheng. 2011. “Context of Use as a Factor in Determining the Usability of in-Vehicle Devices.” *Theoretical Issues in Ergonomics Science* 12 (4): 318–338.

Hawk, S. R., and B. L. Dos Santos. 1991. “Successful System Development: The Effect of Situational Factors on Alternative User Roles.” *IEEE Transactions on Engineering Management* 38 (4): 316–327.

He, J., and W. R. King. 2008. “The Role of User Participation in Information Systems Development: Implications from a Meta-Analysis.” *Journal of Management Information Systems* 25 (1): 301–331.

Herstatt, C., and E. Hippel. 1992. “From Experience: Developing New Product Concepts via the Lead User Method: A Case Study in a ‘Low-Tech’ Field.” *Journal of Product Innovation Management* 9 (3): 213–221.

Hwang, M. I., and R. G. Thorn. 1999. “The Effect of User Engagement on System Success: A Meta-analytical Integration of Research Findings.” *Information & Management* 35 (4): 229–236.

International Organization for Standardization. 1998. *ISO9241-11 Ergonomic Requirements for Office Work with Visual Display Terminals (VDTs) – Part 11: Guidance on Usability*. London: International Organization for Standardization.

International Organization for Standardization. 1999. *ISO 13407, Human-Centred Design Processes for Interactive Systems*. London: International Organization for Standardization.

Ives, B., and M. Olsson. 1981. *User Involvement in Information Systems: A Critical Review of the Empirical Literature*. New York: New York University.

JAMA (Japan Automobile Manufacturers Association). 2004. *Guideline for in-Vehicle Display Systems, Version 3.0*. Tokyo: JAMA.

Kalyuga, S., P. Chandler, and J. Sweller. 1999. “Managing Split-attention and Redundancy in Multimedia Instruction.” *Applied Cognitive Psychology* 13 (4): 351–371.

Karat, J. 1997. “Evolving the Scope of User-centered Design.” *Communications of the ACM* 40 (7): 33–38.

Kaulio, M. A. 1998. “Customer, Consumer and User Involvement in Product Development: A Framework and a Review of Selected Methods.” *Total Quality Management* 9 (1): 141–149.

Kirwan, B., and L. K. Ainsworth. 1992. *A Guide to Task Analysis: The Task Analysis Working Group*. London: Taylor & Francis.

Kujala, S. 2003. “User Involvement : A Review of the Benefits and Challenges.” *Behaviour & Information Technology* 22 (1): 1–16.

Larsson, P., and M. Niemand. 2015. “Using Sound to Reduce Visual Distraction from in-Vehicle Human-machine Interfaces.” *Traffic Injury Prevention* 16: S25–S30.

Lee, J. H. 2008. “User-designer Collaboration during the Early Stage of the Product Development Process.” PhD diss., Queensland University of Technology.

Leplat, J. 1981. “Task Analysis and Activity Analysis in Situations of Field Diagnosis.” In *Human Detection and Diagnosis of System Failures*, edited by Jens Rassumussen, 287–300. New York: Plenum.

Leonard, D., and J. F. Rayport. 1997. “Spark Innovation through Empathic Design.” *Harvard Business Review* 75: 102–115.

Loisel, P., L. Gosselin, P. Durand, J. Lemaire, S. Poitras, and L. Abenhaim. 2001. “Implementation of a Participatory Ergonomics Program in the Rehabilitation of Workers Suffering from Subacute Back Pain.” *Applied Ergonomics* 32 (1): 53–60.

Loup-Escande, E., J.-M. Burkhardt, and S. Richir. 2013. “Anticipate and assess usefulness in the ergonomic design of emerging technologies: a Review.” [Anticiper et évaluer l’utilité dans la conception ergonomique des technologies émergentes: une revue.] *Le Travail Humain* 76 (1): 27–55.

Ma, R., D. B. Kaber. 2007. “Situation Awareness and Driving Performance in a Simulated Navigation Task.” *Ergonomics* 50 (8): 1351–1364.

Macaulay, L. A. 1996. *Requirements Engineering*. Berlin: Springer-Verlag.

Maltz, M., and D. Shinar. 2007. “Imperfect in-Vehicle Collision Avoidance Warning Systems Can Aid Distracted Drivers.” *Transportation Research Part F: Traffic Psychology and Behaviour* 10 (4): 345–357.

Marcus, A. 2004. “Vehicle User Interfaces: The Next Revolution.” *Interactions* 11 (1): 40–47.

Martin, K., S. Legg, and C. Brown. 2013. “Designing for Sustainability: Ergonomics - Carpe Diem.” *Ergonomics* 56 (3): 365–388.

Morag, I., and G. Luria. 2013. “A Framework for Performing Workplace Hazard and Risk Analysis: A Participative Ergonomics Approach.” *Ergonomics* 56 (7): 1086–1100.

McNeese, M. D., B. S. Zaff, M. Citera, C. E. Brown, and R. Whitaker. 1995. “AKADAM: Eliciting User Knowledge to Support

Participatory Ergonomics." *International Journal of Industrial Ergonomics* 15 (5): 345–363.

Moraes, A., and S. Padovani. 1998. "Participatory Evaluation and Design of a Subway Train Cabin." *Participatory Design Conference* 211–217, Seatle, November 12–14.

Nagamachi, M. 1995. "Requisites and Practices of Participatory Ergonomics." *International Journal of Industrial Ergonomics* 15 (5): 371–377.

Najm, W. G., M. D. Stearns, H. Howarth, J. Koopmann, and J. Hitz. 2006. *Evaluation of an Automotive Rear-End Collision Avoidance System. No. DOT-VNTSC-NHTSA-06-01*. Washington, DC: National Highway Traffic Safety Administration.

NHTSA (National Highway Traffic Safety Administration). 2012. *Visual-manual NHTSA Driver Distraction Guidelines for in-Vehicle Electronic Devices*. Washington, DC: National Highway Traffic Safety Administration.

Navarro, J., F. Mars, and J. M. Hoc. 2007. "Lateral Control Assistance for Car Drivers: A Comparison of Motor Priming and Warning Systems." *Human Factors* 49 (5): 950–960.

Nielsen, J. 1990. "Paper versus Computer Implementations as Mock up Scenarios for Heuristic Evaluation." In *Proceedings of the IFIP Tc13 Third Interational Conference on Human-Computer Interaction*, 315–320. Amsterdam: North-Holland.

Nielsen, J. 1994. *Usability Engineering*. Amsterdam: Elsevier Science.

Nielsen, J. 2008. *Bridging the Designer-user Gap*. Nielsen Norman Group. Accessed April 15, 2015. http://www.nngroup.com/articles/bridging-the-designer-user-gap/

Nielsen, J. 2010. "Mental Models." Nielsen Norman Group, Accessed January 4, 2016. https://www.nngroup.com/articles/mental-models/

Nielsen, J. 2012. *Usability 101: Introduction to Usability*. Nielsen Norman Group. Accessed January 4, 2016. https://www.nngroup.com/articles/usability-101-introduction-to-usability/

Norman, D. A. 1993. "Some Observations on Mental Models." *Mental Models* 7 (112): 7–14.

Olsen, G. 2004. "Persona Creation and Usage Toolkit." Interaction by Design, Accessed April 15, 2015. http://www.interactionbydesign.com/presentations/olsen_persona_toolkit.pdf

Pettitt, M., G. E. Burnett, and A. Stevens. 2005. "Defining Driver Distraction." Proceedings of the 12th ITS World Congress, San Francisco, November 6–10.

Pilemalm, S., and T. Timpka. 2008. "Third Generation Participatory Design in Health Informatics-Making User Participation Applicable to Large-Scale Information System Projects." *Journal of Biomedical Informatics* 41 (2): 327–339.

Poulson, D., M. Ashby, and S. Richardson. 1996. *USERfit: A Practical Handbook on User-centred Design for Rehabilitation for Assistive Technology*. Loughborough: HUSAT Research Institute for the European Commission.

Preece, J., Y. Rogers, and H. Sharp. 2011. *Interaction Design: Beyond Human-computer Interaction*. New York: Wiley.

Preece, J., Y. Rogers, H. Sharp, D. Benyon, S. Holland, and T. Carey. 1994. *Human-computer Interaction*. Boston, MA: Addison-Wesley.

Reimer, B., B. Mehler, J. Dobres, J. F. Coughlin, S. Matteson, D. Gould, N. Chahine, and V. Levantovsky. 2014. "Assessing the Impact of Typeface Design in a Text-Rich Automotive User Interface." *Ergonomics* 57 (11): 1643–1658.

Ryan, B., and J. R. Wilson. 2013. "Ergonomics in the Development and Implementation of Organisational Strategy for Sustainability." *Ergonomics* 56 (3): 541–555.

Sanders, E. B. N. 2002. "From User-centered to Participatory Design Approaches." In *Design and the Social Sciences*, edited by J. Frascara, 1–8. London: Taylor & Francis.

Scariot, C. A., A. Heemann, and S. Padovani. 2012. "Understanding the Collaborative-Participatory Design." *Work: A Journal of Prevention, Assessment and Rehabilitation* 41: 2701–2705.

Schade, J., and M. Baum. 2007. "Reactance or Acceptance? Reactions towards the Introduction of Road Pricing." *Transportation Research Part a: Policy and Practice* 41 (1): 41–48.

Shackel, B. 1986. "Ergonomics in Design for Usability." In *Proceedings of the Second Conference of the British Computer Society, Human Computer Interaction Specialist Group on People and Computers: Designing for Usability*, 44–64. Cambridge: Cambridge University Press.

Shneiderman, B. 1992. *Designing the User Interface: Strategies for Effective Human-computer Interaction*. Boston, MA: Addison-Wesley.

Solman, K. N. 2002. "Analysis of Interaction Quality in Human–Machine Systems: Applications for Forklifts." *Applied Ergonomics* 33 (2): 155–166.

Spinuzzi, C. 2005. "The Methodology of Participatory Design." *Technical Communication* 52 (2): 163–174.

Stanton, N. A., and C. Baber. 1992. "Usability and EC Directive 90/270." *Displays* 13 (3): 151–160.

Stanton, N. A., C. Harvey, K. L. Plant, and L. Bolton. 2013. "To Twist, Roll, Stroke or Poke? A Study of Input Devices for Menu Navigation in the Cockpit." *Ergonomics* 56 (4): 590–611.

Stevens, A., A. Quimby, A. Board, T. Kersloot, and P. Burns. 2002. *Design Guidelines for Safety of in-Vehicle Information Systems (Project Report PA3721/01)*. Workingham: Transport Local Government.

Sundin, A., M. Christmansson, and M. Larsson. 2004. "A Different Perspective in Participatory Ergonomics in Product Development Improves Assembly Work in the Automotive Industry." *International Journal of Industrial Ergonomics* 33 (1): 1–14.

Sweller, J. 1988. "Cognitive Load during Problem Solving: Effects on Learning." *Cognitive Science* 12 (2): 257–285.

Torkzadeh, G., and W. J. Doll. 1994. "The Test-retest Reliability of User Involvement Instruments." *Information and Management* 26 (1): 21–31.

Van Der Laan, J. D., A. Heino, and D. De Waard. 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., M. G. Morris, G. B. Davis, and F. D. Davis. 2003. "User Acceptance of Information Technology: Toward a Unified View." *MIS Quarterly* 27 (3): 425–478.

Victor, T., and M. Dozza. 2011. "Timing Matters: Visual Behaviour and Crash Risk in the 100-Car Online Data." *2nd International Conference on Driver Distraction and Inattention*, Gothenburg, September 5–7.

Vink, P., M. Peeters, R. W. M. Gründemann, P. G. W. Smulders, M. A. J. Kompier, and J. Dul. 1995. "A Participatory Ergonomics Approach to Reduce Mental and Physical Workload." *International Journal of Industrial Ergonomics* 15 (5): 389–396.

Weng, C., D. W. McDonald, D. Sparks, J. McCoy, and J. H. Gennari. 2007. "Participatory Design of a Collaborative Clinical Trial

Protocol Writing System." *International Journal of Medical Informatics* 76 (1): S245–S251.

Xie, A., P. Carayon, E. D. Cox, R. Cartmill, Y. Li, T. B. Wetterneck, and M. M. Kelly. 2015. "Application of Participatory Ergonomics to the Redesign of the Family-centred Rounds Process." *Ergonomics* 58 (10): 1726–1744.

Young, M. S., K. A. Brookhuis, C. D. Wickens, and P. A. Hancock. 2015. "State of Science: Mental Workload in Ergonomics." *Ergonomics* 58 (1): 1–17.

Young, K., M. Regan, and M. Hammer. 2007. *Driver Distraction : A Review of the Literature*. Melbourne: Monash University Accident Research Centre.

Young, K., M. Regan, T. J. Triggs, N. Tomasevic, K. Stephan, and E. Mitsopoulos. 2007. "Impact on Car Driving Performance of a following Distance Warning System: Findings from the Australian Transport Accident Commission SafeCar Project." *Journal of Intelligent Transportation Systems* 11 (3): 121–131.

Sub-project 1: Analysis of the context of use

The knowledge of the context of use is recognized as an essential input in any human-centered design process (Bevan, Kirakowski, & Maisse, 1991; Harvey, Stanton, Pickering, McDonald, & Zheng, 2011; Maguire, 2001). Indeed, products have no intrinsic usability, but rather an ability to be usable in a specific context, i.e. with the specified users, having specified goals, performing specified tasks in a specified environment (Bevan, 2001).

In this thesis, identifying and specifying the context of use was therefore an essential first step to have an accurate image of our object of study (MPV HMI) and users. The data of these activities were used in the second sub-project to define the scope of the design activities, as inputs for the user-centered design, and to select representative drivers for the participatory design sessions. Outcomes were also used in the third sub-project, to conduct the assessment in a realistic context.

1. Objectives

The objective of this sub-project was to identify and specify the context of use for which multi-purpose vehicles (MPV) HMI are intended (i.e. drivers, usages, and activities). Indeed, the application case of this thesis concerned a specific range of trucks (MPV) covering diverse usages, environments, and users. In addition, trucks are not sold as standard, each truck is “tailor-made” with several variants. Having a good representation of HMI configurations used by users is therefore essential.

2. Method

In a first study, analyses were conducted on a database of 5 273 Renault Trucks MPV (registered in France in 2013). Descriptive statistics presented MPV usages and applications. A Multiple Correspondence Analysis (MCA) described in a synthetic way the large number of variables used to characterize vehicles. Finally, a Hierarchical Clustering was performed to create clusters of vehicles based on their HMI configurations.

In a second study, a survey was filled out by 68 MPV drivers. The goal was to characterize MPV drivers with information such as general aspects (e.g. gender, age), job related information (e.g. vehicle, number of deliveries per day), their relation to HMI and their expectations.

3. Highlights and application

Results showed that usages are diverse (about 10 categories), with various applications, and HMI configurations. The cluster analysis distributed the 5 273 vehicles in four groups based on their HMI. These four clusters described different and specific types of HMI configurations.

The data from these studies helped to determine the scope of the design activity: as controls were very distributed between the vehicles, the design case chosen was the instrument cluster. For the participatory design, these data enabled to select representative participants of end-users. Moreover, for the concepts assessment phase, the context of assessment has been implemented to match as closely as possible the context of use of the first cluster of vehicle (representing 60% of the multi-purpose trucks).

Report I

Identify and specify MPV HMI Context of use

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Identify and specify MPV HMI Context of use.

Volvo Group Trucks Technology
Internal report – 2015

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Summary

The knowledge of the HMI context of use (i.e. characteristics of the users, tasks and environment in which HMI are used) is an essential input for HMI conception. This report presents two studies aiming at defining MPV HMI context of use. The first study is an analysis of MPV trucks registered in France in 2013, and more particularly of their HMI configurations. Activities for which trucks are used and HMI configurations associated are described. Moreover, data analysis enabled to identify 4 clusters of trucks based on their HMI, to provide a synthetic vision of the market. The second study presents the results of a survey aiming at improving driver knowledge. Sixty-eight MPV drivers answered a questionnaire on their profile, their job, their actual HMI, and their expectations for a future HMI. These findings will allow having a better representation of our users and on usages of each HMI parts (for what activity, in which environment, etc.) for future projects.

1. Introduction

1.1. HMI design

Human-machine interfaces (HMI) define all devices that enable communication between technologies and their user. In a truck, the driver can communicate with the vehicle (e.g. controls on the dashboard to engage a function), and the vehicle can provide information to the driver through the different interfaces (e.g. the vehicle speed is displayed on the instrument cluster).

HMI conceivers have to specify many aspects of the interface such as which information to display to the driver, how to display it, the layout of controls and information, the control characteristics, the logic of interaction, etc. The objective is to optimize safety, usability, and acceptance during HMI use. HMI conceivers take their decisions based on their knowledge on the usages and the users, technical constraints, and cognitive ergonomics.

Nowadays, the development of HMI concepts follows a human-centered design process (International Organization for Standardization, 2010). The human-centered design process splits into three stages through an iterative process: 1) analysis, 2) concept design, and 3) concept assessment. The first phase of analysis aims at specifying user, environment, and technical requirements. Methodological tools such as surveys, activity analysis or focus groups were already used in the company to collect these data. However, the data gathered were often limited by the fact that they were collected on a small sample of customers, and the generalization can be difficult. A stronger input for HMI design would be to have a wider vision of who are our users, what are their activity and their actual HMI, and have a broader access to their needs and expectations.

1.2. HMI Context of use

The context of use can be defined as all the characteristics of the users, tasks and environment in which HMI are used. User factors can cover different information such as their goals, their age, their relation to new technologies, if the population of users is composed of more than one user type, etc. Environment factors include the luminosity conditions, the frequency of use, the duration of the task, etc. For in-vehicle devices, six major aspects of the context of use are identified in the literature (Harvey et al., 2011): dual task environment, environmental conditions, range of users, training provision, frequency of use, and uptake. In our case study (the HMI of Multi-purpose Vehicles [MPV]), to identify and specify the context of use is essential for several reasons.

First, to consider the context of use can improve HMI usability. Bevan (2001) stated that a product does not have “intrinsic usability” rather “a capability to be used in a particular context”. The extent to which a HMI is usable depends on the context, i.e. the specified users, having specified goals and needs, performing specified tasks in a specific environment. User experience or training provision can lead to different choices in term of HMI complexity, due to the varying importance of the ‘learnability’ criterion. Similarly, the frequency of use is important, not only in term of prioritization, but also to know on what functions a particular work will be performed for the criterion of memorability. Regarding the range of users, age and experience are essential information as inputs for HMI design. Older drivers could have a degradation of their physiological, sensory, cognitive and motor abilities; while novice drivers could have more difficulties to deal with the dual task environment (the primary driving task requiring more attention).

Second, to take into account the context of use is important for road safety. The dual-task environment in which in-vehicle interfaces are used implies a careful consideration of the potential impact on safety (Fastrez & Haué, 2008). For multi-purpose trucks, different environments can lead to different considerations for HMI design (e.g. night or daylight, glare of sunlight, road and traffic conditions).

Third, a better knowledge of MPV HMI context of use can provide a greater contextual validity for the assessment phase. Indeed, before the design phase, the context of use is a major source of information for establishing design requirements. During the assessment phase, HMI professionals should ensure that the concept meet these requirements. To increase validity, the context of measurement should then match the context of use. Similarly, the sample of tests participants should correspond to the real end-users. For example, previous articles reported the impact of user factors on a product evaluation: a novice user would focus more on the “holistic impression and styling”, whereas a user with more experience would be able to offer opinions on a wider range of aspects (Khalid & Helander, 2004).

Study 1: Identify and specify MPV usages

1. Introduction

At Renault Trucks, the Multi-Purpose Vehicle (MPV) range is composed of three different vehicles dedicated to diverse usages (from city distribution to light construction; Fig. 1).

Figure 1. Pictures of the Renault Trucks vehicles included in the MPV range. From left to right: C (250-320 ch, 18-26 T, cab 2,3m); D Wide (250-320 ch, 18-26 T, cab 2,3m); D (210-280 ch, 10-18 T, cab 2,1m)

All MPV have the same instrument cluster and instrument panel configuration (Fig. 2). Therefore, besides the constraints linked to the dual-task environment, the specificity of MPV HMI is to be used in various road environment (urban, extra-urban, close to construction sites, etc.), by various types of drivers, and for different tasks and applications.

Figure 2. The instrument panel (common to the C, D wide, and D) and the instrument cluster (common to all MPV)

A clear definition of MPV HMI context of use is essential to increase our knowledge on HMI usages, frequency of use, users, etc. Moreover, in a cost-efficient perspective, context of use can bring information about which aspects to prioritize.

2. Objectives

The objectives of this study were the followings:

- The first objective was to define MPV usages and applications
- The second objective was to analyze the rate of sales for each HMI part and to link it with the usages

Note. For the second objective, only partial results are presented in the thesis for confidentiality reasons (no exact description of the sales volumes of the parts).

3. Method

3.1. Material

Two main databases were used for the analyses:

- First, the French national registration document (year 2013) contained information about the brands, models, bodyworks and applications of each vehicle registered in 2013.
- Second, an internal database at Renault Trucks contained all the variants for each vehicle manufactured:
    - A variant describes one part of the vehicle, for example, the variant ‘Radio’ indicates if the vehicle was sold with a MP3 radio, a basic CD radio, a radio predisposition, or no radio at all.
    - The VINs (Vehicle Identification Number) allowed to link the two databases, and to find the HMI combination of each RT MPV registered in France in 2013. The vehicles included in the sample were part of the previous generation of Renault Trucks MPV Range (i.e. Midlum, Access, Premium D, and Lander; Fig. 3).

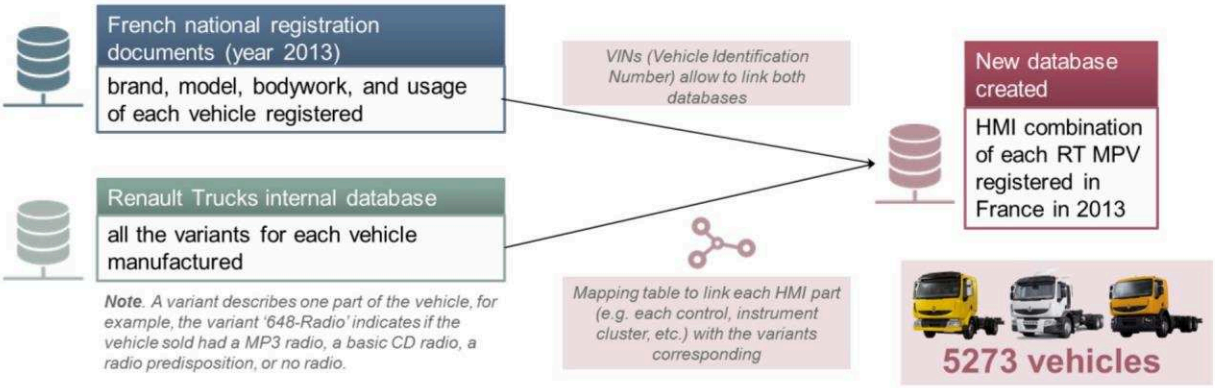


Figure 3. Two databases were linked to obtain a new database with 5273 multi-purpose vehicles registered in France in 2013. For each vehicle, several information was available such as the brand, the model, the bodywork, the application, and the configuration of HMI in the cab (for example if the vehicle had steering wheel switches or not).

3.2. Data acquisition and analysis

A first sort has been performed on the French national registration documents to classify multi-purpose vehicles against other ranges (i.e. light duty, heavy duty, and special vehicles). The list of the vehicles selected for all brands is available in Appendix 1. Descriptive statistics were used to describe MPV usages and applications. Then, a mapping table has been created to link each HMI part (e.g. each control, type of instrument cluster) with the variants corresponding. After the linkage between the two databases, exploratory multivariate data analyses were performed using the R software and the additional package FactoMineR. The goals were to:

- Illustrate clearly the large amount of variables,

- Collect information on potential relationship between some variables (e.g. the characteristic 'withOffRoad' could be related to 'withRearDiffLock' which are two functions used on rough roads),
- Characterize the groups of trucks that have a similar HMI configuration.

A Multiple Correspondence Analysis (MCA) has been performed on all MPV trucks of the sample. This statistical tool was chosen because trucks are described by a set of categorical variables. In the analysis, active variables were each HMI parts of the truck (e.g. variable 'Air conditioning' with two modalities 'withAirConditioning' and 'withoutAirConditioning'). Three illustrative characteristics were used as supplementary categorical variables: usages, bodyworks, and truck models.

Finally, a Hierarchical Clustering has been performed to create clusters of individuals based on their HMI configurations. The number of cluster has been determined automatically by R based on the loss of total inertia gain. Euclidian metric was used to calculate distances and the method of Ward was used to build the tree.

3.3. Sample description

5 273 vehicles were analyzed in the sample (all Renault Trucks MPV registered in France in 2013). Among them, 244 were Renault Trucks Lander, 3 103 were Renault Trucks Midlum, and 1 926 were Renault Trucks Premium D.

4. Results

4.1. MPV usages and applications

4.1.1. The destinations of MPV

Description. Renault Trucks MPVs are mostly destined to Europe (and France in particular). 45% of RT MPVs were sold in France in 2013. The second destination is Algeria with 10% of MPV RT but it is also a gate to Maghreb and Africa. Globally, vehicles destined for Europe represent 72% of the RT MPV. 12 countries represent 90% of MPV destinations, with the half in Europe (Fig. 4).

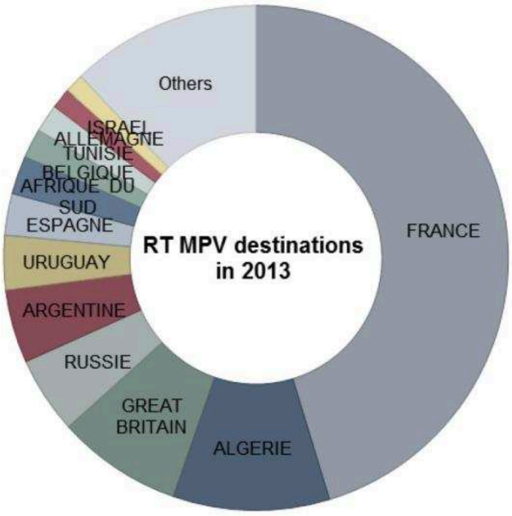


Figure 4. Countries of destinations for Renault Trucks MPV vehicles in 2013.

Interpretation. The sample used in this study based on the French national registration documents (year 2013) accounts for 45% of MPVs sold. The evaluation phase of HMI concepts can be done with French drivers, who represent almost half of RT MPV users. Nevertheless, the variety of languages to display has to be considered in term of usability (e.g. high readability with every language).

4.1.2. Renault Trucks MPV usages

Description. The principal customers are renters and administrations, accounting for 46% of MPVs (Fig. 5).

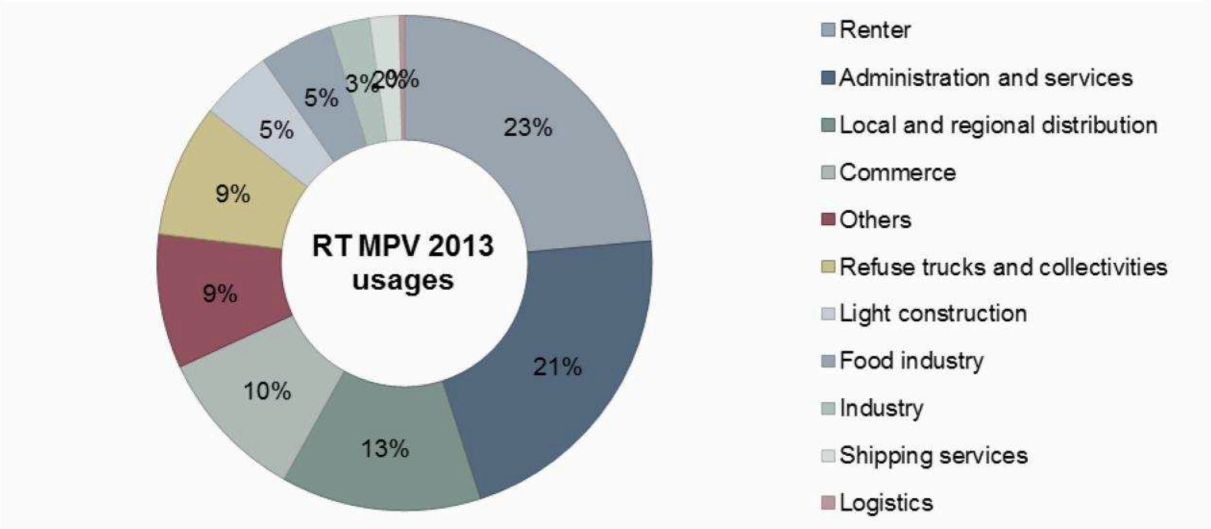


Figure 5. Usages of the French MPVs in 2013.

Interpretation. The fact that the first activity is renting implies that HMI concepts have to present a great learnability. The user will want to achieve a high level of usability in a short time (and often without instructions at the handover).

Moreover, the diversity of usages is clearly represented here. For example, yhe same HMI is used for refuse trucks and local regional distribution, i.e. different driving speed, different road condition, different traffic environment, different numbers of stops per day, etc.

4.1.3. Renault Trucks MPV bodyworks

Description. Van body and conditioned body trucks represent about 40% of MPV (mainly destined for renters and local and regional distribution). Refuse collection body and fire trucks represent more than 20% of MPV (destined for administration and collectivities; Fig. 6).

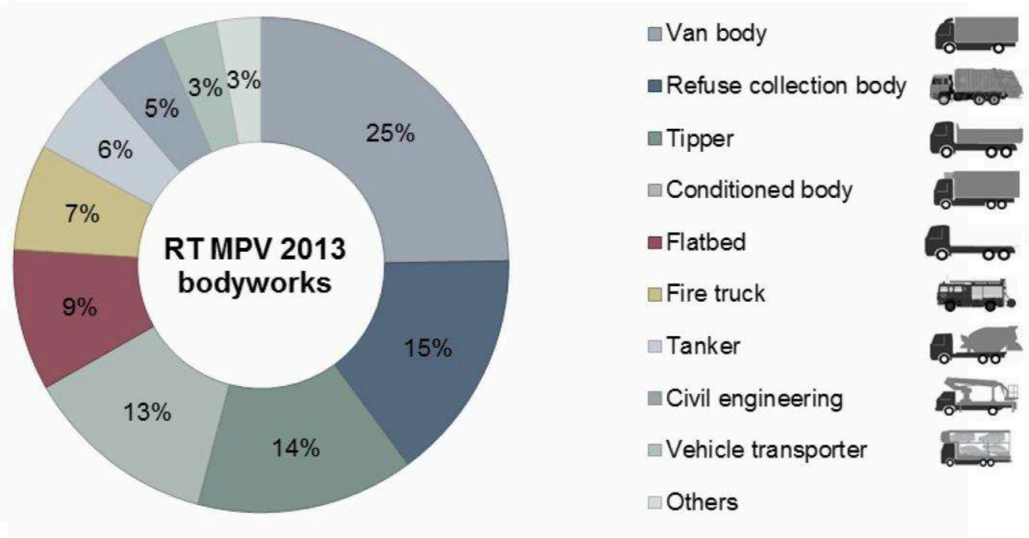


Figure 6. Usages of the MPV vehicles in 2013.

Interpretation. Even if HMI conceivers have no impact on the bodyworks instruments, bodybuilders can send warnings or information to the driver through the instrument cluster. Some bodyworks (e.g. refuse collection trucks) are likely to display information in the instrument cluster. Considering the diversity and the specificity of bodyworks, it has to be considered during the design of the instrument cluster.

4.2. MPV HMI configurations

4.2.1. Descriptive rating of the presence of HMI parts in Multi-Purpose Trucks

Description. Eleven HMI parts are present in 2/3 of the vehicles. Among them, the hazard warning switch is mandatory. On the other side, 24 HMI parts are present for less than 10% of the vehicles. The MPVs of the sample have an average of 13.7 switches (on right and left dashboard areas, headershelf, and gear lever console area).

Interpretation. These results confirm that there is a high diversity of HMI configuration, with HMI parts that have a limited rate of presence. This result can influence layout choices and prioritization during a new HMI conception.

Note. This part has been reduced in the thesis for confidentiality reasons.

4.2.2. MPV HMI Factor mapping

Description. The multiple component analysis (MCA) was run on the 57 variables defining the HMI configuration (with the 5 273 vehicles in the sample) (Fig. 7).

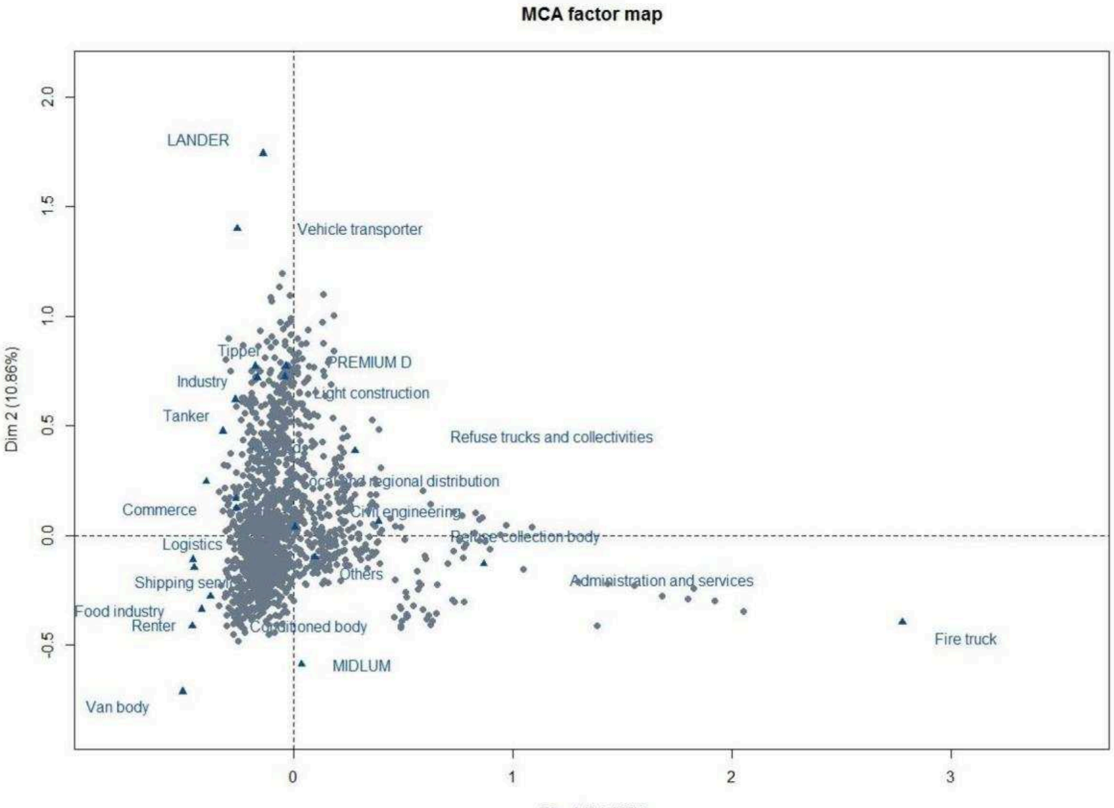


Figure 7.Multiple Correspondence Analysis 2D Factor Map. Each grey point represents a truck and Blue points indicate supplementary categorical variables modalities (Models, Usages, and Bodyworks).

MCA revealed 15 components explaining together more than 75% of the variance (76.5%). The two first components (on which data are visualized) had eigenvalues greater than .10 and explained respectively 14.12% and 10.86% of the total variance.

Interpretation. Visual inspection of the factor map plot indicates that some HMI configurations are specifics and correspond to particular bodyworks and usages (e.g. 'Fire truck' bodywork is isolated on the map; it means that the HMI configurations corresponding to this bodywork are specifics).

4.2.3. Clustering of the vehicles according to their HMI configuration

Description. The hierarchical clustering allows gathering the 5 273 trucks of the dataset into a couple of clusters which would correspond to different HMI profiles (Fig. 8). MCA is used as a pre-processing and clusters are presented on the factor map (the two dimensions are the MCA dimensions presented in 4.2.2).

Four clusters of HMI configuration were automatically determined by the hierarchical clustering analysis (based on the loss of inertia per partitioning). Each of the four clusters and their HMI specificities are described in Table 1.

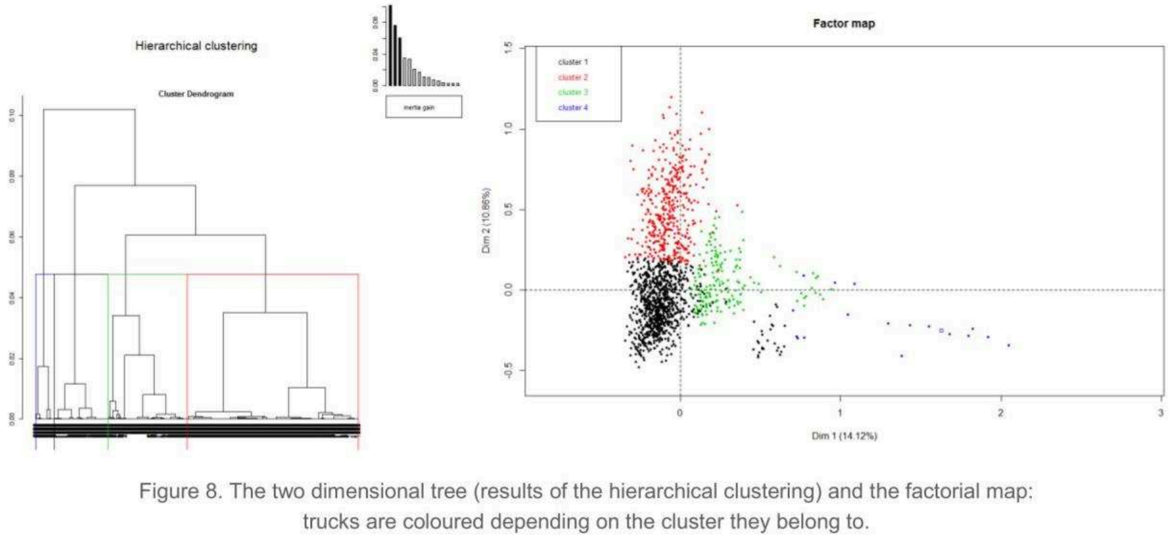


Figure 8. The two dimensional tree (results of the hierarchical clustering) and the factorial map: trucks are coloured depending on the cluster they belong to.

Table 1. Description of the four cluster and their HMI specificities

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	3157 vehicles	1042 vehicles	895 vehicles	179 vehicles
Model and configuration	▪ 82% Midlum and 17% Premium D ▪ 94% of rigid trucks ▪ 99% of 4x2	▪ 73% Premium D and 20% Lander ▪ 57% of rigid trucks with trailer and 36% of rigid trucks ▪ 46% of 6x2 and 38% of 4x2	▪ 70% Premium D and 30% Midlum ▪ 100% of rigid trucks ▪ 59% of 4x2 and 41% of 6x2	▪ 100% Midlum ▪ 99% of rigid trucks ▪ 59% of 4x2 and 41% of 4x4
Bodyworks and Usages	▪ 39% of van body ⇨ mainly renters and distribution ▪ 20% of conditioned body ⇨ mainly renters and distribution ▪ 12% of tipper ⇨ mainly administrations	▪ 37% of tipper ⇨ renters, administrations and collectivities and light construction ▪ 19% of flatbed ⇨ mainly distribution ▪ 15% of tanker ⇨ mainly commerce applications ▪ 13% of vehicle transporters ⇨ mainly distribution and commerce	▪ 74% are Refuse collection trucks ⇨ administrations and collectivities ▪ 14% are Fire trucks ⇨ administrations	▪ 97% are Fire trucks ⇨ administrations
Mean number of switches	12, 6	17,8	13,2	12,1

Interpretation.

The **first cluster** represents 60% of RT MP Trucks registered in 2013 in France. The vehicles included are mainly van and conditioned body, with some tipper. The main application is local and regional deliveries (directly or through renters). Their HMI is basic and driving oriented (basic IC, radio CD, cruise control on the dashboard). The only function relating to the usage is suspensions control, on the dashboard for half of them.

The **second cluster** represents 20% of RT MP Trucks registered in 2013 in France. The vehicles included are mainly tipper, tanker, and vehicle transporters. The main applications are commerce and light construction (directly or through administrations and collectivities). Their HMI is more specific with functions dedicated to their usage (e.g. rear wheel diff lock to drive on rough roads). The comfort is higher: most of the vehicles have air conditioning, cruise controls switches on the steering wheel, robotized gearbox, suspension remote, and half of them have a radio MP3. The mean numbers of switches on the dashboard is higher than for other clusters.

The **third cluster** represents 17% of RT MP Trucks registered in 2013 in France. The vehicles included are refuse collection trucks and fire trucks. Their HMI is specific with functions dedicated to their usage (e.g. automatic gearbox and auto neutral function due to the high number of stops during refuse collection).

The **fourth cluster** represents only 3% of RT MP trucks registered in 2013 in France. The vehicles included are fire trucks. Their HMI is also very specific with functions dedicated to the driving on rough roads (e.g. 4x4 configurations, muddy site, PTO1). The comfort level is poor: no radio, no air conditioning, and no cruise control; except for the instrument cluster which is mainly the ‘high’ variant.

5. Discussion

Lessons learned. As expected, MPV usages and applications are diverse. Compatibility with all usages has to be a key point during the HMI conception. The high proportion of renters (23%) implies a need to promote learnability. A work on HMI efficiency is also needed regarding the part of fire trucks in the sample (7%).

Concerning HMI parts repartition, a high number of functions have a limited presence, and it can help HMI conceivers when they face decisions requiring trade-offs.

The 4 clusters resulting of this study are interesting because they present very specific HMI configurations and are also linked to the usages. They can provide a basis for conception and a target to ensure that a new concept will match with all configurations.

Limitations. The first limitation is the date of the data (2013). Indeed, data collected concern the previous range of Renault Trucks vehicles. However, there were no more recent registration documents available. These analyses should be replicated on the new range for more validity.

Second, the HMI parts present in a vehicle do not only depend on the customer need or the usages for which the truck is dedicated. Indeed, some commercial packs imply automatically the presence of some functions.

Third, the usages reported here are not very detailed. The data source was the French registration documents and the classification is not very precise (e.g. local and regional distributions are in the same category).

Finally, the presence of functions provides no information on their frequency of use, although this measure is determinant for HMI conception.

Future researches perspectives. An activity analysis could complement this study by measuring frequency of use for each HMI part.

Study 2: Identify and specify MPV Drivers

1. Objectives

The objectives of this survey were:

- To specify MPV drivers' profiles
- To increase knowledge on MPV drivers relation to HMI
- To prioritize their HMI needs and expectations

2. Method

2.1. Material

The questionnaire was composed of 29 items (Fig.9). These items were grouped in four parts: 'your profile'; 'your job'; 'your dashboard'; and 'your idea dashboard'.

All questions are presented in appendix 2.

In the first part, general characteristics were addressed (e.g. gender, age). In the second part, job related information was addressed (e.g. vehicle, number of deliveries per day). In the third and the fourth parts: 11 target HMI functions were selected to collect information on actual use and expectations.

The 11 target functions were the following:

- Speed limiter
- Cruise control
- Eco coaching systems
- Parking heater
- Driving times information in the instrument cluster
- Bluetooth connection to the cell phone
- Tire pressure management system
- Integrated GPS
- Reverse camera
- Trip and fuel consumption information in the instrument cluster
- Load indicator system

These functions were chosen because they represented a special interest for HMI professionals.

Questions 'Your profile'	Questions 'Your job'	Questions 'Your dashboard'	Questions 'Your ideal dashboard'
General ▪ Gender ▪ Age ▪ Country of residence ▪ Vision assessment ▪ Colour-blindness assessment ▪ Hearing assessment ▪ Car driven **Connectivity** ▪ Relation to new technologies ▪ Number of cell phones (mobile phones and smartphones) ▪ Technologic devices brought in the cab ▪ Mobile apps used related to the job	**Experience** ▪ Years of experience **Attitude** ▪ Pride to be a truck driver **Company** ▪ Number of drivers in the company ▪ Usage sector **Vehicle** ▪ Vehicle type ▪ Bodywork ▪ Brand and model ▪ Other vehicles driven **Activity** ▪ Number of deliveries per day ▪ Mean for order transmission ▪ Number of night slept in the truck per week ▪ Single or double crew	**Attitude** ▪ Perceived importance of the HMI ▪ Perceived use performance of the HMI ▪ Judgment of their actual HMI **HMI actual use** ▪ Frequency of use of the 11 target functions (detailed above)	**Wish list** ▪ Perceived importance of the 11 target functions (detailed above) ▪ Open question

Figure 9. Description of the items of the questionnaires grouped by questionnaire parts.

2.2. Data acquisition

The questionnaire was built with Google Form (free application). A non-branded approach was used, and drivers did not know the origin of the questionnaire. A first diffusion was made online through Facebook. 10 Facebook groups dedicated to trucks drivers were selected. 195 questionnaires were completed, but only 34 respondents were MPV drivers.

Therefore, a second diffusion was made in a training center specialized in logistics and transport professions. All drivers attended an upgrade training (mandatory in France every 5 years). 74 questionnaires were collected, including 34 corresponding to MPV drivers. Descriptive statistics were used for the analysis.

2.3. Sample description

A total of 269 participants completed the questionnaire. Among these participants, 5 were removed due to incomplete or inappropriate answers, and 169 participants were heavy duty truck drivers. Thus, the final analyses were performed on a total of 68 MPV drivers.

3. Results

3.1. MPV drivers profile

3.1.1. General

Description. Drivers are mainly men (96%) between 18 and 66 years old (M=38; ±10) (Fig. 10). Respondents live in France (97%), in Belgium (1.5%), or in Swiss (1.5%).

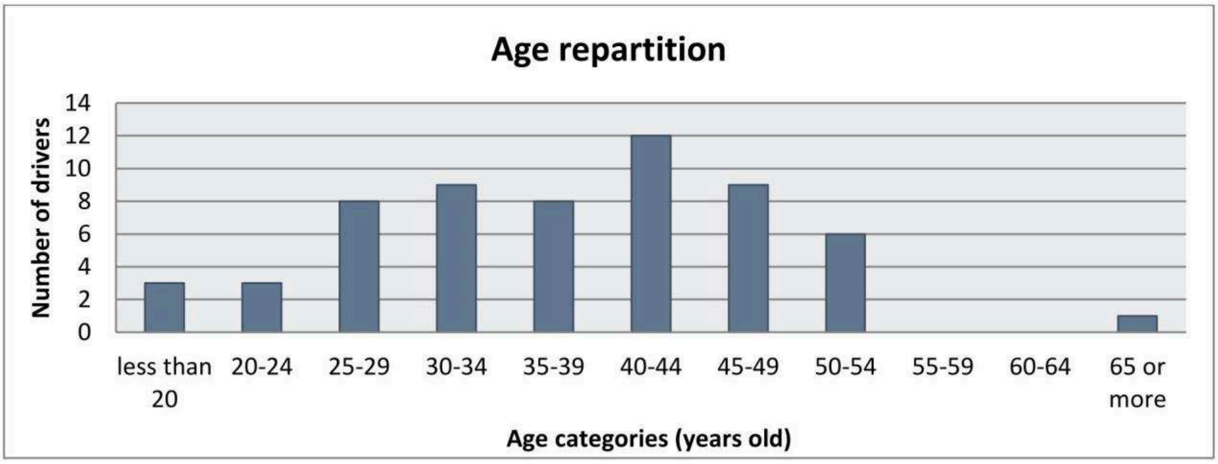


Figure 10. Ages of participants grouped into categories

88% of them evaluate their vision as good or very good (1 driver quoted it bad, and 7 as average). 6% are color-blind. 94% report having a good or very good hearing (1 driver quoted it very bad, and 3 as average).

Concerning the car driven: 23.5% drive a Peugeot, 19% a Renault, 9% a Citroen, 9% an Opel, 4% a Volkswagen, 3% a Toyota, 3% a BMW, and 3% a Ford.

Interpretation. The percentage of women in the sample seems to be representative of the global population of trucks drivers (3% in France in 2012; OPTL, 2013). MPV drivers are quite young, but drivers over 45 years old (24%) have to be considered during HMI conception and evaluation as they can be prone to a cognitive decline.

The fact that drivers report a good vision and audition is important for HMI conception. Indeed, it is a good input while creating sound warnings, or deciding the size of the texts to display. The percentage of color-blind drivers is coherent with the rate in the total men population in France (about 8%).

3.1.2. Connectivity

Description. To the question concerning their relation to new technologies (Likert scale in five points, from '*quite reluctant to new technologies*' to '*always at the cutting edge of technology*'): 75% of drivers answered 4 or 5/5; 22% answered 3; and 4% answered 1 or 2/5.

Most of the drivers have one or two cell phones. Among the 47% who have one phone, 69% are smartphones. Among the 44% of drivers who have two phones, 73% are one mobile and one smartphone. Globally, 76% or the respondents have at least 1 smartphone.

Concerning technological devices that are often brought in the cab (multiple choice questions with 4 response options: tab, laptop, GPS, Speed camera alert system): the GPS is often brought in the cab by 71% of drivers, 18% bring a tablet, 10% bring a laptop, and 7% often bring a speed camera alert system.

An open question was asked about the Mobile apps used in relation to their job. GPS apps (Google Maps, Waze, TomTom, Michelin, Mappy) are cited by 40% of drivers. Other apps cited are far behind: social networks ('Facebook'; 3 drivers /68), phone book app ('Pages Jaunes'; 2/68), speed camera alert app ('iCoyote'; 1/68), and own company app (1/68).

Interpretation. The fact that ¾ of MPV drivers are comfortable with technology and the familiarity with smartphones is interesting for HMI conception. Indeed, it indicates that they can adapt to new interaction modes (e.g. swiping on a touchscreen). However, ease of use and learnability has to be also assessed for the remaining 25%.

The high importance of GPS (both external device and mobile app) indicates a need, and direction information should have a convenient location on the dashboard.

3.2. MPV drivers job

3.2.1. Experience and attitude

Description. MPV's driver experience is distributed as follows:

- 7%: 1 year or less
- 29%: From 1 to 5 years
- 15%: From 5 to 10 years
- 49%: More than 10 years

Most of drivers are proud or very proud to be delivery truck driver (79%), 15% are neither proud nor ashamed of being truck driver (3/5), and 6% rated their pride to 2/5.

Interpretation. Few MPV drivers are beginners; we can therefore expect that they know well HMI functions. Despite the fact that driving is less important for MPV applications than for heavy transportation (e.g. in city distribution, they are more delivery men than drivers), drivers report pride and motivation for their job.

3.2.2. Company

The size of companies is distributed. Regional distribution is highly represented; a question with sub-categories could have been more informative (Fig. 11).

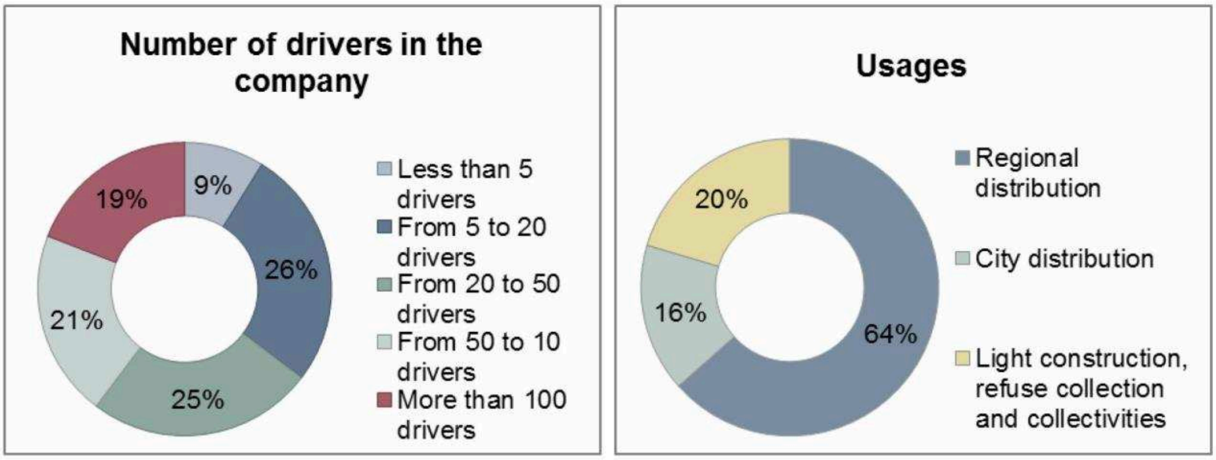


Figure 11. Company size and activity

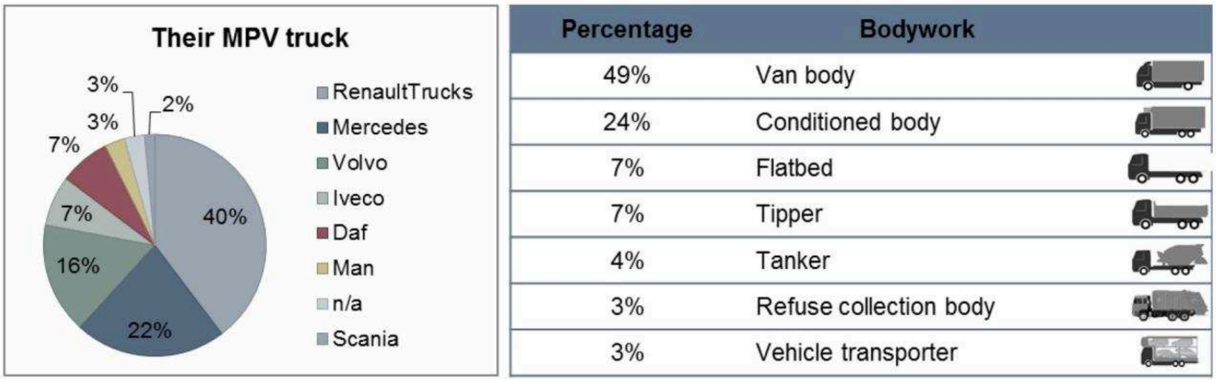
3.2.3. Vehicle

Description. 22% of drivers never drive another truck than their usual vehicle. 40% of respondents drive a Renault Trucks (Fig. 12). Main bodyworks are van body (49%) and conditioned body (24%).

Interpretation. The brand repartition is close to the real distribution in France. Only Volvo seems to be over-represented (16% versus 3% in France 2013 registrations). Similarly, Iveco seems to be under-represented (7% versus 14% in France 2013's registrations).

Bodyworks follow approximately the real distribution. However, tipper and refuse collection body are under-represented (respectively 14% and 15% in France 2013's registrations).

The fact that most of drivers drive regularly other trucks imply that HMI usability will be increased by a good learnability and memorability.



Percentage	Bodywork
49%	Van body
24%	Conditioned body
7%	Flatbed
7%	Tipper
4%	Tanker
3%	Refuse collection body
3%	Vehicle transporter

Figure 12. Brand and bodywork of participants' trucks.

3.2.4. *Activity*

Description. The number of deliveries per day is quite variable:

- 10%: From 20 to 50 deliveries per day
- 25%: From 10 to 20 deliveries per day
- 32%: From 5 to 10 deliveries per day
- 29%: Less than 5 deliveries per day

The most common mean for order transmission is Paper/planning (for 54% of drivers). Then, mobile phone is used for 26% of drivers. Finally, 15% of drivers receive their orders through telematics systems. None of the drivers sleeps in the truck, and they all drive in single crew.

Interpretation. The number of deliveries is important to know for HMI conceivers to better understand HMI context of use; the high number of entry/exit implies some constraints (e.g. concerning the messages to display at the Bluetooth linkage between the cell phone and the radio).

3.3. MPV drivers relation to HMI

3.3.1. Attitude

Description. 50% of respondents quoted HMI importance at 5/5 ('V*ery important*'). 35% considered it as '*important*' (4/5). 15% answered the average score (3/5).

At the question evaluating their perceived self-performance with HMI (from 1:'*I have difficulties to perform the actions I want to do*'; to 5: '*I know all switches and functions of the dashboard*'): 41% answered 5/5; 49% answered 4/5; 9% answered the average (3/5); and one driver answered 1.

63% of drivers estimated that their actual HMI information available on the instrument cluster (number, nature, ease of read, etc.) is good or excellent. On the other hand, 37% consider it as bad or average (2 and 3/5).

Interpretation. HMI is considered as important for the respondents and they know well how to use truck functions.

We could not link the satisfaction with their actual HMI with the brand due to the reduced size of the sample and the high variability in brands repartition.

3.3.2. HMI actual use

Description. For the 11 target functions, frequency of use (in four points between '*very rarely*' and '*very often*') were asked when drivers had the function in their truck (Fig. 13).

	Percentage of respondents having the function
Speed limiter	79%
Cruise control	90%
Eco coaching systems	69%
Parking heater	79%
Driving times information in the instrument cluster	91%
Bluetooth connexion to the cell phone	59%
Tire pressure management system	41%
Integrated GPS	21%
Reverse camera	28%
Trip and fuel consumption information in the instrument cluster	94%
Load indicator system	22%

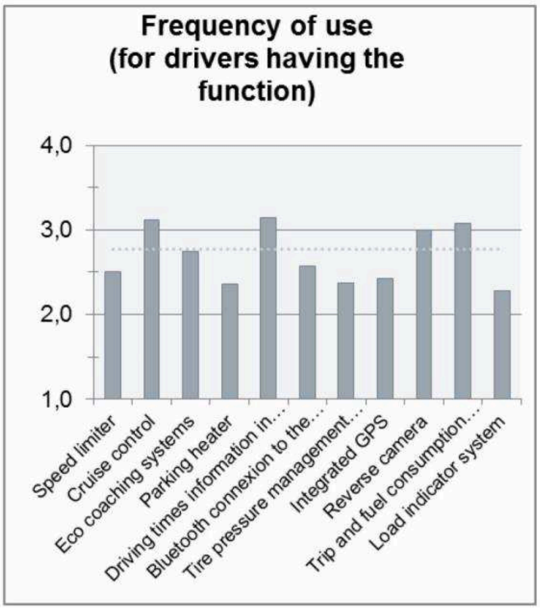


Figure 13. Table representing the percentage of respondents having the function, and graph of frequency of use (among drivers having the function) for each target function (1: 'very rarely'; 2: 'rarely'; 3: 'often'; 4: 'very often'). The dashed line indicates the average frequency of use considering the 11 functions.

Interpretation. Some percentages of respondents having the function appear surprisingly high (e.g. for speed limiter system or parking heater). We can think that drivers responding to the questionnaire were confused due to the vocabulary chosen (e.g. speed limiter could represent for some of them the speed restricted electronically to 90km/h). Those methodological limitations are addressed in the discussion of this document.

However, '*reverse camera*' or '*load indicator system*' can be external devices added by companies, and not provided by the truck manufacturer.

4 functions seem to distinguish themselves in term of frequency of use:

1) Driving times information in the instrument cluster
2) Cruise control
3) Trip and fuel consumption information in the instrument cluster
4) Reverse camera

For HMI conception, information frequently used is a key point which has to be specifically studied to ensure high usability and reduced distraction. Further investigations have to be made to determine the best way (i.e. location, nature, moment, etc.) to display the information to the driver.

3.4. MPV drivers HMI needs and expectations

3.4.1. Perceived importance of each target function proposed

Interpretation. 4 functions seem to distinguish themselves in term of perceived importance (their score are over the average importance for all functions combined):

1) Cruise control
2) Driving times information in the instrument cluster
3) Trip and fuel consumption information in the instrument cluster
4) Integrated GPS

However, all functions have a mean score between 3.8 and 4.5, it means that all target functions are considered as useful to drivers for their activity (Fig.14).

It seems like drivers having the function have a more definite opinion on the function usefulness than drivers who do not have the function.

This prioritization form MPV drivers point of view can help HMI conceivers for resources allocation and decision making.

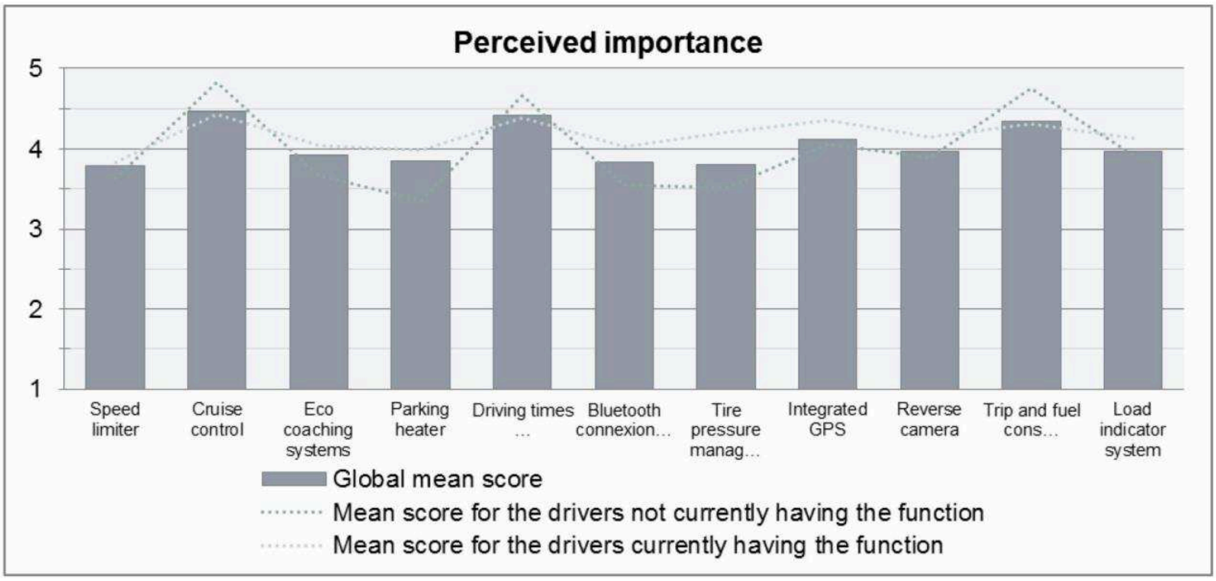


Figure 14. Perceived importance of the 11 target functions (Likert scale from 1: 'useless' to 5: 'must-have'). The dark green dashed line indicates the mean perceived importance for drivers who report not currently having the function. The light green dashed line indicates the mean perceived importance for drivers who report having the function.

Description. A detailed consideration of the answers repartition helps to discriminate perceived usefulness of the function (Fig.15).

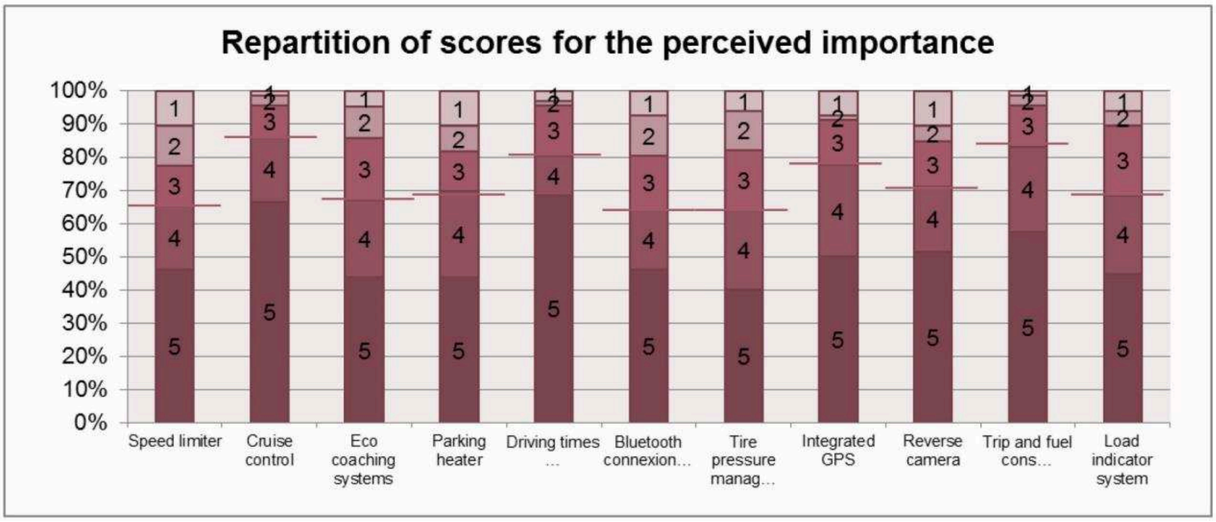


Figure 15. Repartition of scores for the perceived importance of the 11 target functions (Likert scale from 1: 'useless' to 5: 'must-have').

For each function, the red line crossing the plot represents the separation between answers indicating that the function is useful (scores 4 and 5/5) and answers indicating that the function is useless or moderately useful (scores 1,2 and 3/5).

Interpretation. Based on this representation, 'Reverse camera' seems also to be part of the important functions. Indeed, 69% of drivers estimate that this function is useful (of which 72% consider it as a must-have).

3.4.2. Open question: other 'must have' ideas

Description. An open question was also asked to drivers. The MPV drivers 'must have' ideas added are:

- 'GPS as standard';
- 'integrated hands-free kit for phone';
- 'independent air conditioning';
- 'DVD player in the cab';
- 'Alcohol lock;
- 'distance sensor for maneuvers';
- 'Retarder as standard'.

Interpretation. Once again, the vocabulary used could mislead driver. Indeed, the driver asking for 'integrated hands-free kit for phone' did not understand properly the 'Bluetooth connection' target function proposed. Those methodological limitations are addressed in the discussion of this document.

4. Discussion

Lessons learned. MPV drivers have diverse profiles (in term of ages, experience, activity, etc.). Contrary to preconceived ideas, MPV drivers are not only young people (the average age is 38). Few MPV drivers are beginners; we can therefore except they know well HMI functions. They are mainly comfortable with technology and smartphones, and HMI is important for them (Fig. 16). Within the 11 target functions proposed: ‘Cruise control’, ‘Driving times information in the instrument cluster’, ‘Trip and fuel consumption information in the instrument cluster’, ‘Integrated GPS’ and ‘Reverse camera’ are prioritized information for the drivers.

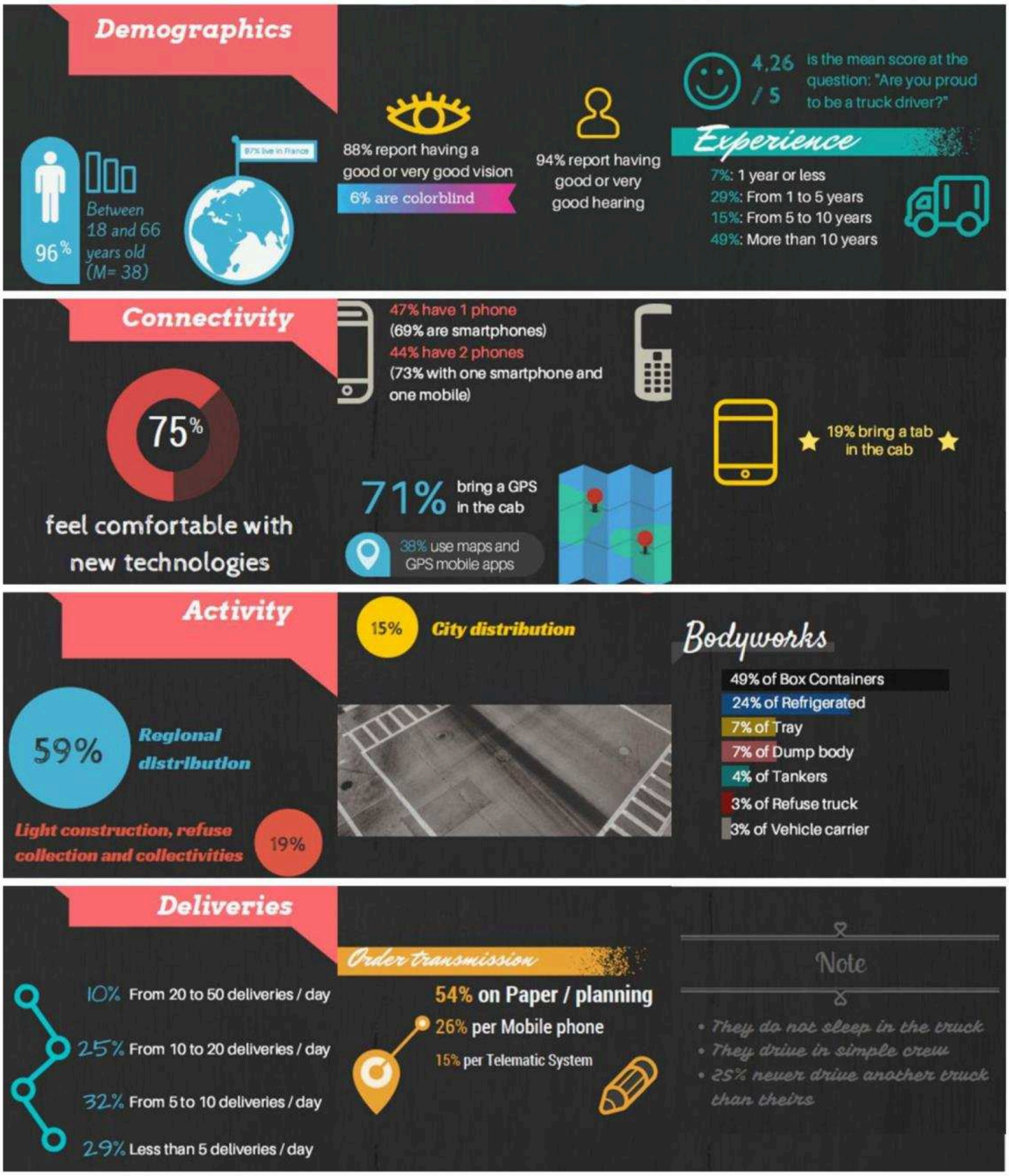


Figure 16. Summary of main findings

Limitations. The first limitation is the size of the sample (68 respondents). With an online diffusion, we hoped to collect more data. This limitation did also not allow performing multivariate data analyses and clustering. However, this method was less costly (time and money) than face-to-face interviews for the same sample size. Concerning the representativeness of the sample, not all activities are represented (here mainly regional distribution, city distribution, and light construction). Moreover, the fact that most of the respondents came from Facebook can overestimate the results on their level of connectivity.

Second, some limitations are associated with the tool used (questionnaire). The number of items is limited, and multiple choice questions were mostly used. Only 11 target functions were investigated (due to questionnaire length and duration). Some questions were difficult to analyze (e.g. car driver, other trucks driven) without further explanations from the respondent (level of equipment of the car, frequency of use of other trucks, etc.). Besides, some important questions were filled in an incomplete way (open questions). For the vehicle brand and model, drivers often only wrote the brand of their truck.

Third, although the questionnaire had been pre-tested with drivers, the vocabulary for some items was not enough understandable. For example, some drivers answered that the Bluetooth connection is not important in the trucks, but added a remark on the usefulness of a hands-free communication with the mobile phone. Similarly, the high rate of drivers reporting having a speed limiter compared to the number of speed limiter sold on the market may suggest that they answered for the mandatory limitation of the trucks to 90km/h (and not for the speed regulation system).

Future researches perspectives. Online surveys seem to be adapted for heavy duty trucks drivers (in our case 169 respondents). This method is easy to implement and less costly than face-to-face interviews.

Conclusion

Highlights

The knowledge of HMI context of use (i.e. characteristics of the users, tasks and environment in which HMI are used) is an essential input for HMI conception. The first study aimed at identifying and specifying MPV usages and applications. 5273 vehicles and their HMI configuration were analyzed (Renault Trucks MPV registered in France in 2013). Results showed that usages are diverse (about 10 categories), but 3 main applications represent more than the half of the vehicles: renters, administrations and services, and local and regional distribution. The three bodyworks corresponding (accounting for 54% of MPV) are van body, refuse collection body and tipper (conditioned body represent also more than 1 vehicle on 10). A further analysis revealed that a high number of HMI functions have a limited presence in MPV sold (almost the half of HMI parts are present in less than 10% of the vehicles). A cluster analysis defined 4 clusters of trucks based on their HMI configuration. It is interesting to see that only 4 types of configuration (and very specific) can describe the range, and that they are highly linked with usages. The first cluster represents 60% of RT MPV, vehicles are mainly van and conditioned body, with some tipper for local and regional deliveries (directly or through renters); and a basic and driving oriented HMI. The second cluster represents 20% of RT MPV; vehicles are mainly tipper, tanker, and vehicle transporters for commerce and light construction (directly or through administrations and collectivities). Their HMI is more specific (functions dedicated to their usage) with a high number of switches on the dashboard and a great comfort level. The third cluster represents 17% of RT MPV; vehicles are refuse collection trucks and fire trucks. Their HMI is specific with functions dedicated to their usage. The fourth cluster represents only 3% of RT MPV (fire trucks), with a specific HMI and a poor comfort level (except for the IC).

The second study aimed at specifying MPV drivers' profiles and increase knowledge on their relation to HMI. A survey composed of 29 items was proposed online (Facebook) and in a training center. Sixty-eight questionnaires were collected from MPV drivers. Results showed that MPV drivers' average age is 38 (with an equivalent repartition in all age class). Few MPV drivers are beginners; we can therefore except they know well HMI functions. They are mainly comfortable with technology (and smartphones), and HMI is important for them. Questions aiming to prioritize their HMI needs and expectations highlighted 5 'must-have': 'Cruise control', 'Driving times information in the instrument cluster', 'Trip and fuel consumption information in the instrument cluster', 'Integrated GPS' and 'Reverse camera'.

Perspectives

These findings are an essential basis for the MPV HMI conception. It is also an important input to provide contextual validity to the assessment phase. The four clusters identified and the activities associated will help to define scenarios and tasks for the evaluation tests. Moreover, those results inform us quantitatively about the representativeness of our context of measurement (e.g. French participants are representatives for 45% of MPV drivers).

References

Bevan, N. (2001). International standards for HCI and usability. *International journal of human-computer studies*, *55*(4), 533-552.

Fastrez, P., & Haué, J. B. (2008). Designing and evaluating driver support systems with the user in mind. *International journal of human-computer studies*, *66*(3), 125-131.

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.

International Organization for Standardization (2010). *ISO 9241-210 - Ergonomics of human-system interaction – Human-centered design for interactive systems*. International Organization for Standardization.

Khalid, H. M., & Helander, M. G. (2004). A framework for affective customer needs in product design. *Theoretical Issues in Ergonomics Science*, *5*(1), 27-42.

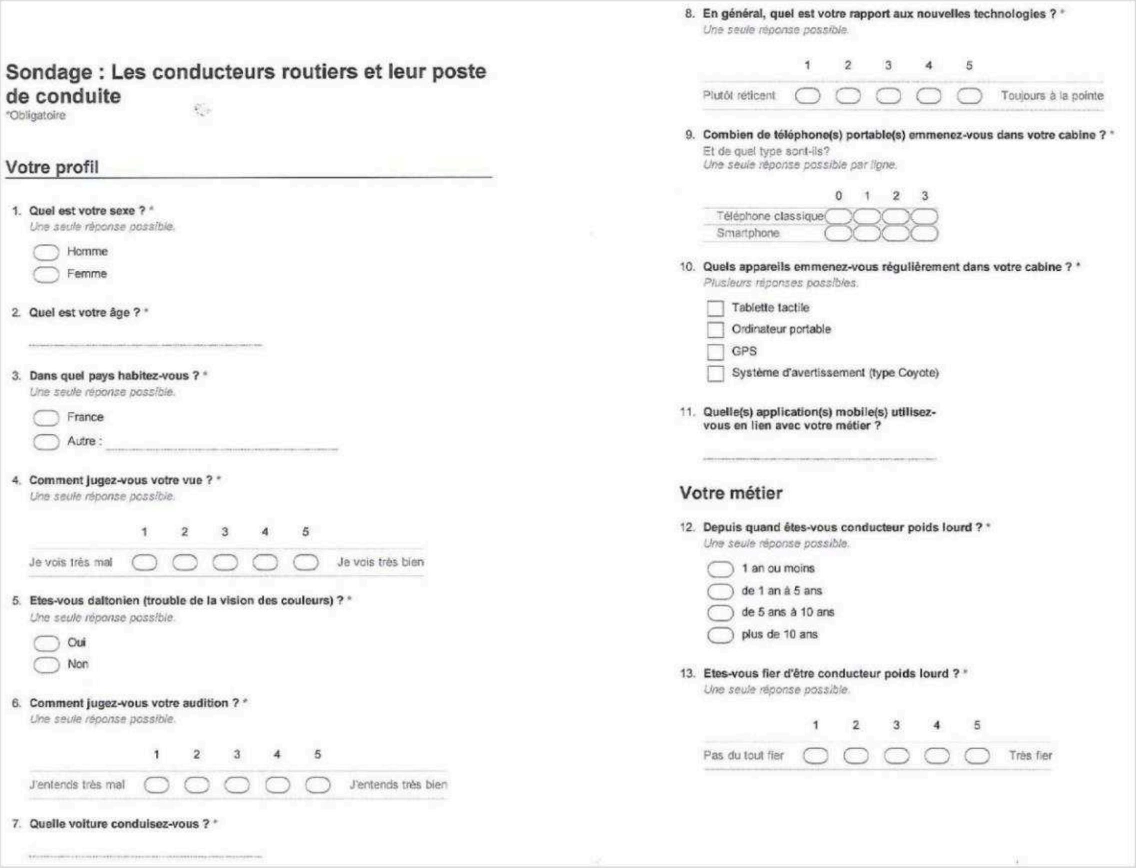
OPTL (2013), *2013 Report of the Prospective Observatory of occupations and qualifications in the transports and Logistics*. OPTL. Retrieved from http://www.optl.fr/parution/rapport-annuel/RA-OPTL-15jan2013.pdf

Appendices

Appendix 1: Brands models considered for the MPV range

Brand	Model
Renault Trucks	Lander / C, Premium Distribution / D Wide, Midlum / D, Access
Iveco	Eurocargo, Stralis Hi-Street, Eurocargo 4x4
Man	Tgl, Tgm
Daf	Lf, Cf
Volvo	Fl, Fe
Mercedes	Atego, Axor, Antos
Scania	P Series

Appendix 2: Questionnaire form



Sondage : Les conducteurs routiers et leur poste de conduite
*Obligatoire

Votre profil

1. **Quel est votre sexe ? ***
Une seule réponse possible.
○ Homme
○ Femme

2. **Quel est votre âge ? ***
____

3. **Dans quel pays habitez-vous ? ***
Une seule réponse possible.
○ France
○ Autre : ______________________

4. **Comment jugez-vous votre vue ? ***
Une seule réponse possible.

	1	2	3	4	5	
Je vois très mal	○	○	○	○	○	Je vois très bien

5. **Etes-vous daltonien (trouble de la vision des couleurs) ? ***
Une seule réponse possible.
○ Oui
○ Non

6. **Comment jugez-vous votre audition ? ***
Une seule réponse possible.

	1	2	3	4	5	
J'entends très mal	○	○	○	○	○	J'entends très bien

7. **Quelle voiture conduisez-vous ? ***
____

8. **En général, quel est votre rapport aux nouvelles technologies ? ***
Une seule réponse possible.

	1	2	3	4	5	
Plutôt réticent	○	○	○	○	○	Toujours à la pointe

9. **Combien de téléphone(s) portable(s) emmenez-vous dans votre cabine ? ***
Et de quel type sont-ils?
Une seule réponse possible par ligne.

	0	1	2	3
Téléphone classique	○	○	○	○
Smartphone	○	○	○	○

10. **Quels appareils emmenez-vous régulièrement dans votre cabine ? ***
Plusieurs réponses possibles.
☐ Tablette tactile
☐ Ordinateur portable
☐ GPS
☐ Système d'avertissement (type Coyote)

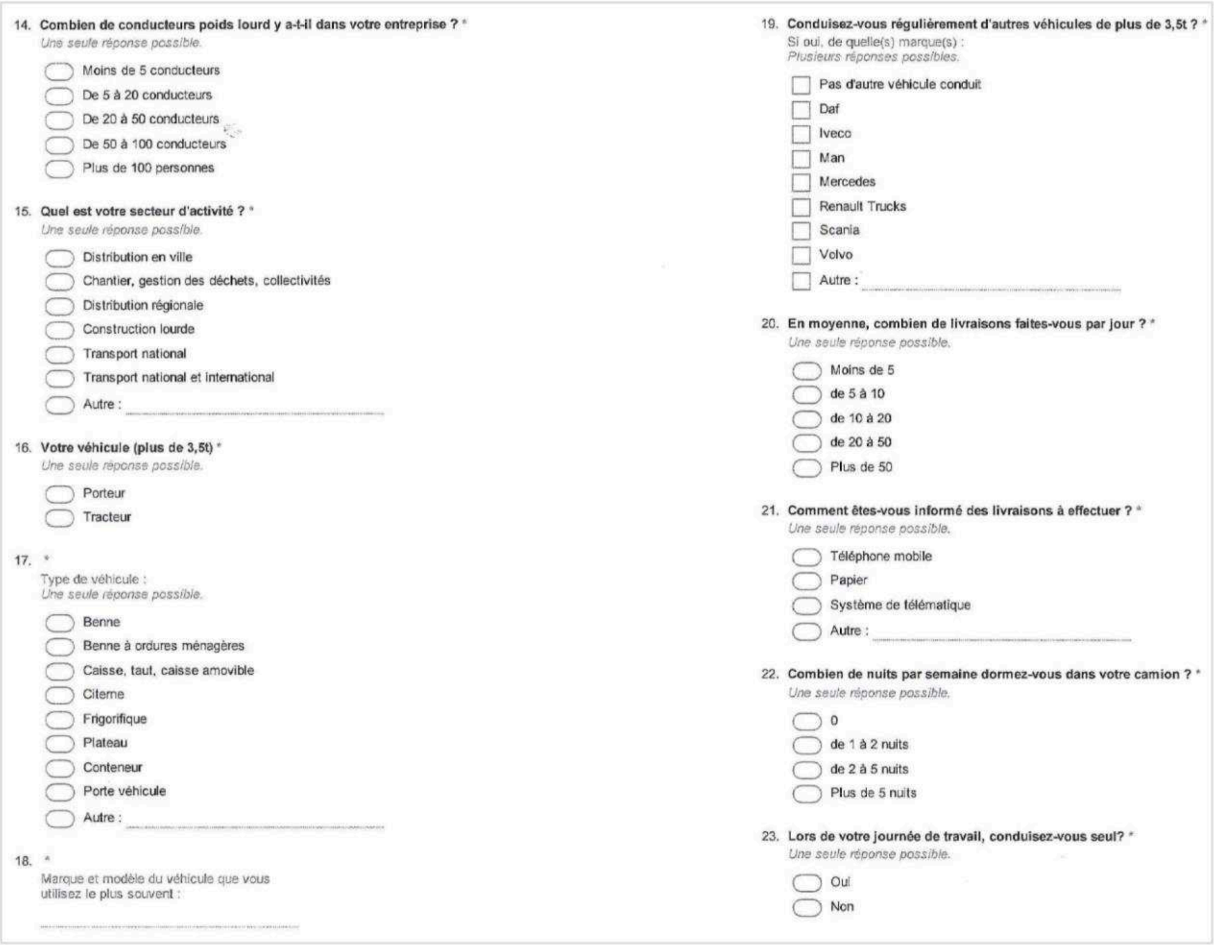
11. **Quelle(s) application(s) mobile(s) utilisez-vous en lien avec votre métier ?**
____

Votre métier

12. **Depuis quand êtes-vous conducteur poids lourd ? ***
Une seule réponse possible.
○ 1 an ou moins
○ de 1 an à 5 ans
○ de 5 ans à 10 ans
○ plus de 10 ans

13. **Etes-vous fier d'être conducteur poids lourd ? ***
Une seule réponse possible.

	1	2	3	4	5	
Pas du tout fier	○	○	○	○	○	Très fier



14. **Combien de conducteurs poids lourd y a-t-il dans votre entreprise ?** *
Une seule réponse possible.
○ Moins de 5 conducteurs
○ De 5 à 20 conducteurs
○ De 20 à 50 conducteurs
○ De 50 à 100 conducteurs
○ Plus de 100 personnes

15. **Quel est votre secteur d'activité ?** *
Une seule réponse possible.
○ Distribution en ville
○ Chantier, gestion des déchets, collectivités
○ Distribution régionale
○ Construction lourde
○ Transport national
○ Transport national et international
○ Autre :

16. **Votre véhicule (plus de 3,5t)** *
Une seule réponse possible.
○ Porteur
○ Tracteur

17. *
Type de véhicule :
Une seule réponse possible.
○ Benne
○ Benne à ordures ménagères
○ Caisse, taut, caisse amovible
○ Citerne
○ Frigorifique
○ Plateau
○ Conteneur
○ Porte véhicule
○ Autre :

18. *
Marque et modèle du véhicule que vous utilisez le plus souvent :

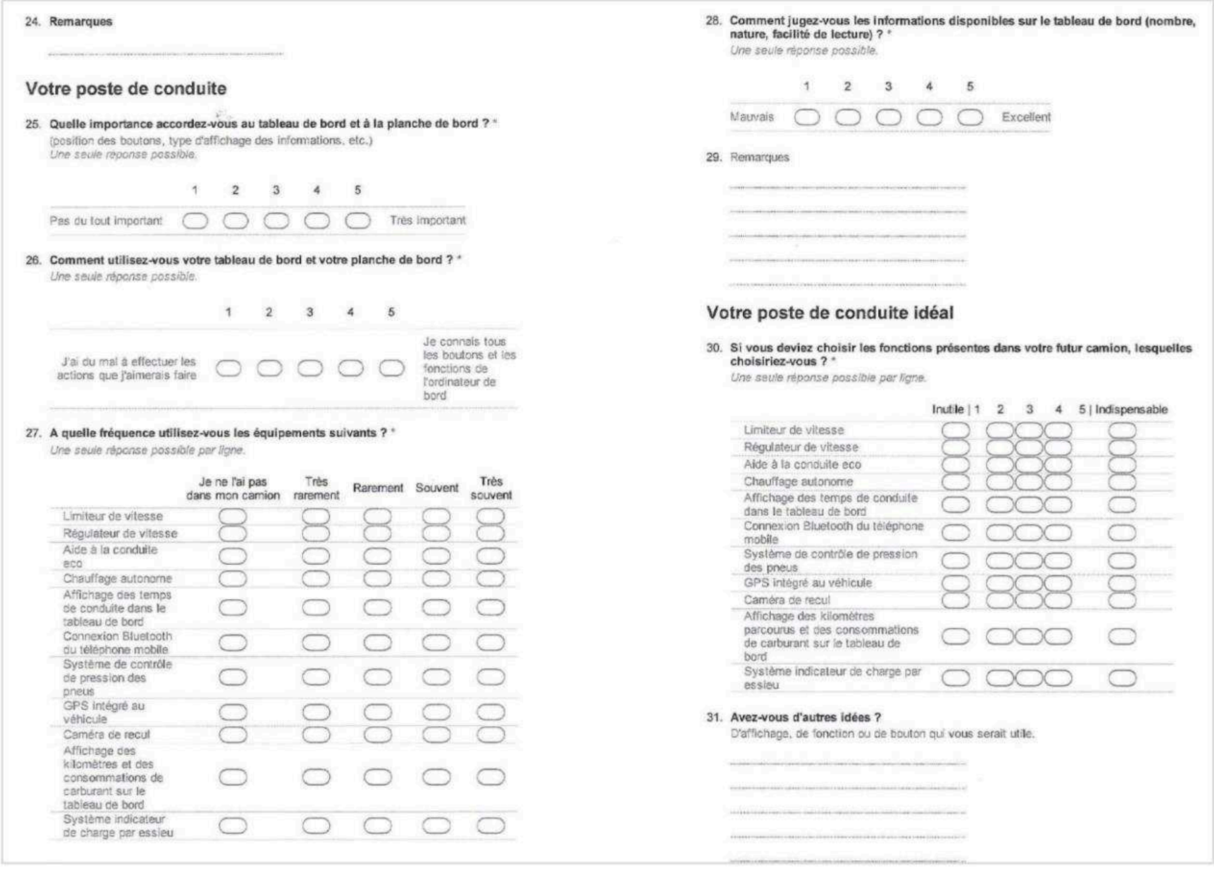
19. **Conduisez-vous régulièrement d'autres véhicules de plus de 3,5t ?** *
Si oui, de quelle(s) marque(s) :
Plusieurs réponses possibles.
☐ Pas d'autre véhicule conduit
☐ Daf
☐ Iveco
☐ Man
☐ Mercedes
☐ Renault Trucks
☐ Scania
☐ Volvo
☐ Autre :

20. **En moyenne, combien de livraisons faites-vous par jour ?** *
Une seule réponse possible.
○ Moins de 5
○ de 5 à 10
○ de 10 à 20
○ de 20 à 50
○ Plus de 50

21. **Comment êtes-vous informé des livraisons à effectuer ?** *
Une seule réponse possible.
○ Téléphone mobile
○ Papier
○ Système de télématique
○ Autre :

22. **Combien de nuits par semaine dormez-vous dans votre camion ?** *
Une seule réponse possible.
○ 0
○ de 1 à 2 nuits
○ de 2 à 5 nuits
○ Plus de 5 nuits

23. **Lors de votre journée de travail, conduisez-vous seul?** *
Une seule réponse possible.
○ Oui
○ Non



24. **Remarques**

Votre poste de conduite

25. **Quelle importance accordez-vous au tableau de bord et à la planche de bord ?** *
(position des boutons, type d'affichage des informations, etc.)
Une seule réponse possible.

	1	2	3	4	5	
Pas du tout important	○	○	○	○	○	Très important

26. **Comment utilisez-vous votre tableau de bord et votre planche de bord ?** *
Une seule réponse possible.

	1	2	3	4	5	
J'ai du mal à effectuer les actions que j'aimerais faire	○	○	○	○	○	Je connais tous les boutons et les fonctions de l'ordinateur de bord

27. **A quelle fréquence utilisez-vous les équipements suivants ?** *
Une seule réponse possible par ligne.

	Je ne l'ai pas dans mon camion	Très rarement	Rarement	Souvent	Très souvent
Limiteur de vitesse	○	○	○	○	○
Régulateur de vitesse	○	○	○	○	○
Aide à la conduite eco	○	○	○	○	○
Chauffage autonome	○	○	○	○	○
Affichage des temps de conduite dans le tableau de bord	○	○	○	○	○
Connexion Bluetooth du téléphone mobile	○	○	○	○	○
Système de contrôle de pression des pneus	○	○	○	○	○
GPS intégré au véhicule	○	○	○	○	○
Caméra de recul	○	○	○	○	○
Affichage des kilomètres et des consommations de carburant sur le tableau de bord	○	○	○	○	○
Système indicateur de charge par essieu	○	○	○	○	○

28. **Comment jugez-vous les informations disponibles sur le tableau de bord (nombre, nature, facilité de lecture) ?** *
Une seule réponse possible.

	1	2	3	4	5	
Mauvais	○	○	○	○	○	Excellent

29. Remarques

Votre poste de conduite idéal

30. **Si vous deviez choisir les fonctions présentes dans votre futur camion, lesquelles choisiriez-vous ?** *
Une seule réponse possible par ligne.

	Inutile | 1	2	3	4	5 | Indispensable
Limiteur de vitesse	○	○	○	○	○
Régulateur de vitesse	○	○	○	○	○
Aide à la conduite eco	○	○	○	○	○
Chauffage autonome	○	○	○	○	○
Affichage des temps de conduite dans le tableau de bord	○	○	○	○	○
Connexion Bluetooth du téléphone mobile	○	○	○	○	○
Système de contrôle de pression des pneus	○	○	○	○	○
GPS intégré au véhicule	○	○	○	○	○
Caméra de recul	○	○	○	○	○
Affichage des kilomètres parcourus et des consommations de carburant sur le tableau de bord	○	○	○	○	○
Système indicateur de charge par essieu	○	○	○	○	○

31. **Avez-vous d'autres idées ?**
D'affichage, de fonction ou de bouton qui vous serait utile.

Sub-project 2: Concepts design

In this sub-project, three concepts were defined using different processes. In order to compare rigorously the outcomes of the three processes, the designs were carried out on the same design case and with the same equipment. The only aspect that varied between the three concepts was therefore the design process and the level of user involvement. The three concepts generated during this phase will be evaluated in sub-project 3.

In a first part, the scope of the design activities and the prototyping tool used in this research are described. Then, the user-centered design conducted is presented, with preliminary studies on human-factors recommendations. Finally, the two participatory processes are presented. A more detailed description of the processes methods is presented in Paper V.

1. Common scope and tools for the design processes

1.1. Scope

As mentioned in the introduction, trucks HMI cover many parts of the vehicle such as the controls, the stalks, the remote controls, the steering-wheel switches, or the instrument cluster. However, the sub-project 1 showed that the configurations of controls were very different among trucks. As the benefits of participatory design would rely in part on direct access to drivers' knowledge and experiences, it did not seem adapted to propose to drivers to work on functions they do not use. Besides, the stalks implied technical restrictions for the participatory workshops, particularly because their design is mainly based on standards and regulations which reduces design degrees of freedom. The choice of the design case has therefore moved towards the instrument cluster.

Moreover, instrument clusters presented interesting contemporary challenges related to technological evolutions. Indeed, the instrument clusters tend to become screens, which brings a freedom and a flexibility of design for the interfaces. When instrument clusters were electro-mechanical, the technical constraints were much more present in the development of an interface. To choose the screen instrument cluster as design case was interesting for several reasons:

- To increase knowledge about ergonomic design on this type of support;
- To have a great freedom of conception (few restrictions by the technical aspects);

- The free space to display information is generally smaller than on electro-mechanical displays due to the cost of the screens: there is a need to prioritize the information;
- Possibility to have a high-fidelity prototype that is functional for the assessment;
- In the future, screen instrument clusters can offer personalization possibilities: the stakes and risks are very close to those of participatory design.

Trucks instrument clusters contain a lot of different information (in average more than 900). Everything could not be covered in design sessions for time and technical reasons (difficulty in addressing depth with menus, pages, sub menus, dynamic alerts, etc.). The design therefore focused on essential driving functions (basic HMI reported for the cluster 1 in the sub-project 1). This ensured that the drivers knew and used this information, and this enabled an assessment on the driving simulator. For example, if we had conducted the design session on specific displays such as differential lock (i.e. a function that will put more power on some wheels depending on the choice of the driver, to leave a muddy area for example), drivers might not know this function, and the assessment would have been conducted in a realistic context of use (e.g. construction site). Essential driving functions are also relevant because they have a high frequency of use, and therefore a potentially greater impact on usability, distraction, and acceptance.

1.2. Prototyping tool

For the participatory design sessions, the tool used for conception is a key point. Sanders (2002) pointed out that an appropriate "make-tool" is essential to let users express themselves. A good make-tool would be visual and projective to facilitate exchange between the design stakeholders. As designers and users often do not share a common language and have different cultural backgrounds, the tools should improve communication and cooperation in the design activities (Bruno & Muzzupappa, 2010). Sanders, Brandt, and Binders (2010) classified three types of tools: 2D collages (e.g. timelines, diaries), 2D mapping (e.g. maps, mind mappings) or 3D mock-ups (e.g. using foam, clay, Legos, Velcro-modeling). The choice of the tool depends on the design case.

The conception of a specific prototyping tool was essential for this project. Indeed, in a user-centered design process, designers are professionals and experts in the use of design software. However, for the participatory design, drivers are not qualified in the use of these designers' tools. One of the solutions would be to ask drivers to give instructions to an expert using the computer. In this case, the user would not be directly the designer and some social biases might occur (e.g. social desirability; Scariot, Heemann, Padovani, 2012). Another solution would be to use a directly accessible design tool. This is often the case when “paper-pencil tools” are used. In our case, this would have been problematic for two reasons: the first is that not everyone is comfortable with drawing and the design of an interface requires some detail; the second is that the drawings do not allow a simulation scenario and a self-evaluation of the prototype on a driving simulator. In this case, we would face a limit addressed to the participatory design by Bruno and Muzzupappa (2010): the physical mock-up of the concept often appears late in the development process, causing a delay in discovering design or interaction problems.

The idea was therefore to design a home-made tool with which the driver could create his interface easily and autonomously. A touchscreen was used for the direct access (Fig. 5).

In the prototyping software, some parameters were imposed:

- The size and shape of the stage (active zone of 8 inches);
- 17 functions categories were presented, with a total of 186 different available widgets (Appendix 1);
- Users could not invent new widgets;
- Users had to choose the following information: speed, gearbox information (mode and lever position), retarder, mode and target speed of the ADAS.

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. Widgets were grouped in functions categories to help the user to find the desired information. Users had the possibility to move, resize, or delete widgets on the stage. The touchscreen was installed on a mid-fidelity driving simulator. Thus, the user could see the concept designed replicated behind the wheel (important to auto-assess visibility and accessibility), but above all, he could drive with the concept. During the design session, user could then define the concept on the touchscreen, drive with it, make changes, drive again, etc.

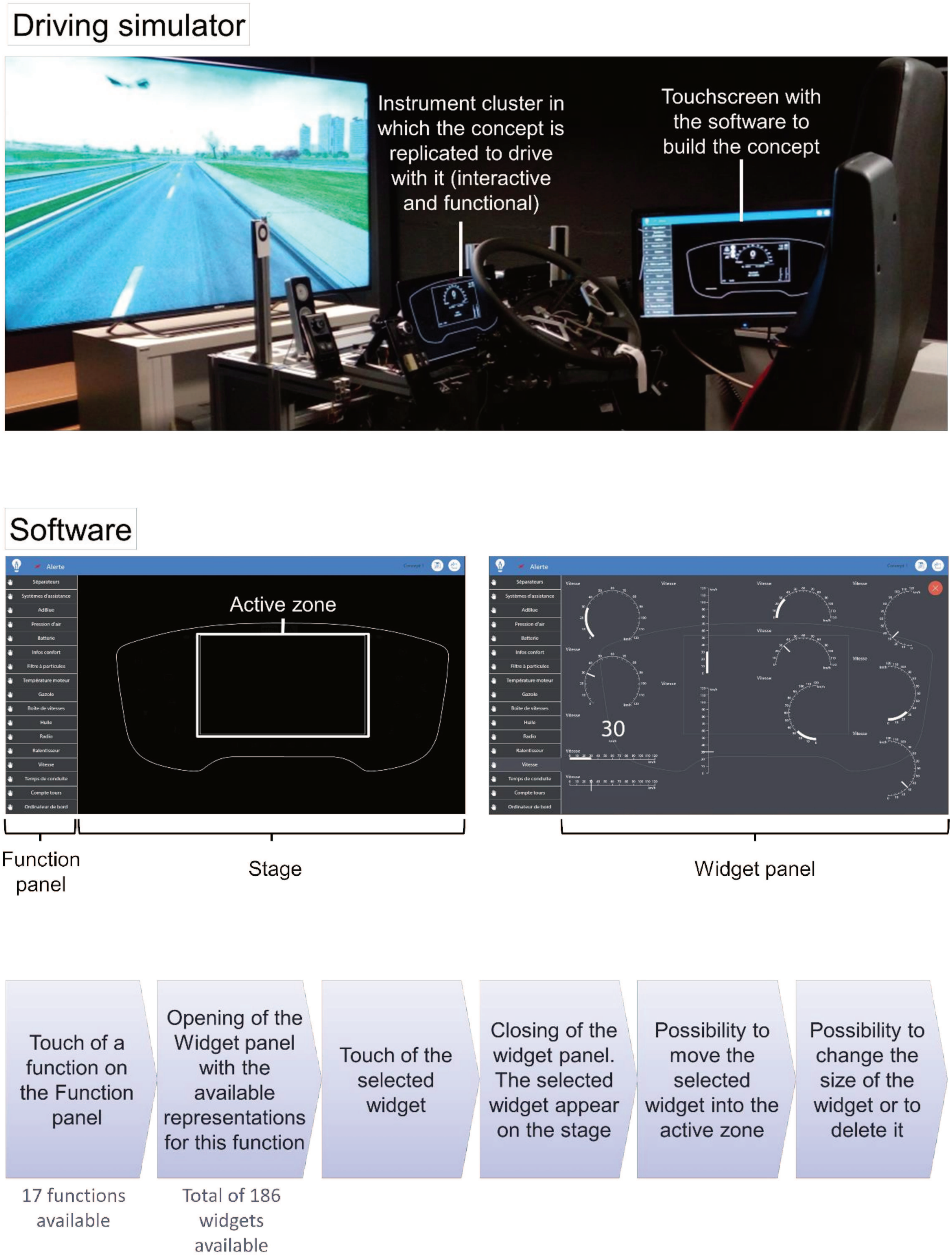


Figure 5: Equipment of the design sessions

2. User-centered design

The goal of the sub-project 2 was to define three concepts of instrument clusters thanks to three processes differing in level of user involvement. In this part, the user-centered design process is exposed. During a user-centered design, experts design concepts based on their knowledge of users, usages, environment of use, and ergonomic recommendations. Prior to design, a review of human-factors guidelines was conducted. This review is presented in Report II. In addition, experiments have been carried out to enrich these recommendations for the design of interfaces on screen instrument clusters. Two experiments were conducted on the design of speedometers (Paper II and III), and a study was carried out on the design of gauges on screen instrument clusters (Paper IV).

2.1. Human-factors guidelines review

2.1.1. Objectives

The objective of this review was to gather existing technical literature, in which guidelines or recommendations were presented to promote usability, distraction and acceptance while designing in-vehicle HMI.

2.1.2. Method

Guidelines, standards, and ergonomic research articles were used in this report. This review addresses the instrument cluster, but also the controls to bring a wider knowledge that the company can use in future projects.

2.1.3. Highlights and application

Recommendations were reported on global aspects (e.g. colors, text), presentation and layout of information and controls, and on controls characteristics. For example, elements spatially close are perceived as belonging to each other (Gestalt law of proximity) and boxes can be used around groups to improve visual perception of grouping (ISO 9241-12, 1998).

This knowledge was used during the design phase by the experts. For example, in the user-centered design concept, 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).

Report II

Human-factors guidelines: a review for the design of trucks HMI

François, M., Crave, P. (2016). Human-factors guidelines: a review for the design of trucks HMI. Volvo Group Trucks Technology. Internal report: unpublished.

Volvo Group Trucks Technology, Complete Vehicle
FVV Lyon, Driver Experience, Driver Interface & Communication

VOLVO
Volvo Group Trucks Technology

Human-factors guidelines: a review for the design of trucks HMI.

Volvo Group Trucks Technology
Internal report – 2016

Authors: Mathilde FRANCOIS and Philippe CRAVE
External collaboration with: Jordan NAVARRO (EMC, University Lyon 2), François OSIURAK (EMC, University Lyon 2), and Alexandra FORT (LESCOT, IFSTTAR)

1. Purpose of the document

1.1. Objectives

During a new human-machine interface (HMI) design, conceivers have to take many decisions, from the choice of the layout of information to controls characteristics. As for all HMI design, their goal is to conceive usable (e.g. easy to use, to learn, satisfying to use) and accepted interfaces (e.g. useful, high willingness to use). However, in-vehicle interfaces are used while driving, which implies other key design goals such as the reduction of visual distraction and an increased interface efficiency (i.e. few time, errors, and cognitive resources consumption required). For example, drivers should use emergency controls in a rapid way (e.g. horn), without having difficulties to find it, without requiring instructions on how to operate it, and while continuing to pay attention to the road. To accomplish these goals, user interfaces should be designed in accordance with human capabilities and limitations. The ISO 9241-210 (2010) strongly recommends considering human factors and user involvement to promote usability. Human factors knowledge is used as input for HMI design, such as technical restrictions, costs information, regulation, industrial trends, brand image, etc. Many documents provide human factors recommendations and guidelines for designing HMI. This document aims at gathering this information for a practical and easy use. References presented in the document give access to more detailed descriptions.

1.2. Scope

This review is leaded within the PhD project 'HMI defined by driver' and follows therefore the PhD scope (i.e. instrument panel, steering wheel switches, primary cluster information, and screen instrument cluster). Alerts and warnings, secondary displays, GPS, sounds, pedals, telematics, cameras, and HUD are not addressed here.

Guidelines and human-factors articles were used in this review. Among guidelines, generic guidelines on visual interfaces (e.g. colors) refer to electronic visual displays in general (e.g. desktop computers). Guidelines dedicated to motor vehicles were also used. Among them, many guidelines were intended for cars interfaces and not for commercial vehicles and trucks (see details in the reference table). The principal differences between car drivers and trucks drivers to keep in mind are that:

- Truck drivers spend more time behind the wheel (up to 56 h in any given work week) than car drivers
    - The literature reports that the sustained mental workload associated with long-term tasks may cause performances deterioration (Lim et al., 2010; cited in Bedinger, Walker, Piecyk, & Greening, 2015). Long-term exposure to noise and vibration that may affect the ability to engage with vehicle feedback (Majumder et al., 2009; cited in Bedinger et al., 2015). They could present stronger stress reactions to traffic conditions and more risky driving behaviors (Oz et al., 2010; cited in Bedinger et al., 2015).
- Truck drivers use their vehicle in a professional context
    - The literature reports that they present higher technical knowledge (Donmez et al., 2006; cited in Bedinger et al., 2015). Naturalistic data suggested that professional drivers have faster response times when performing an evasive manoeuver when compared to car drivers (Dozza, 2013). They would also be more heightened critical toward automation (Bedinger et al., 2015).
- Vehicle characteristics impact drivers' behavior
    - The driving position is higher in trucks than in cars. The normal line of sight is more distant to instrument cluster and panel. Moreover, the number of controls and information to display is much higher than in cars.

The specificity of the activity (i.e. volume and vehicle load, specific regulations) and the socio-professional context do not allow a generalization of all results concluded with car drivers. However, the high cognitive processes (e.g. learning, memory, automation, attentional processes) involved when using a car in-vehicle interface are also involved with commercial vehicles interfaces. Thus, the generic recommendations and guidelines reported here can be used as input information for truck HMI design.

Note.

The recommendations reviewed in this document have to be considered as information on existing studies. Some of these principles may conflict each other. For example, the headlight master control is often located on the left panel while the headlamp flasher and beam switching is located on a stalk. The principle of functional grouping and frequency of use are then competing (Turner & Green, 1987). Appropriate trade-offs need to be made according to the HMI specialist knowledge.

2. Global recommendations

2.1. Colors

Colors can be used to provide organization consistency to a visual interface (e.g. layout, grouping, coding). Concerning the **number of colors** to use, guidelines recommend minimizing the number of colors simultaneously used. Generic recommendations mention no more than 11 different colors for accurate identification, and no more than six colors for a rapid visual search (including white, grey and black; ISO 9241-303, 2008). For in-vehicle information displays, Campbell, Carney and Kantowitz (1997) recommend not to exceed 4 colors for casual users and 7 colors for experienced long-term users. On their side, Stevens, Quimby, Board, Kersloot, & Burns (2002) recommend a maximum of 5 different colors. Anyway, when colors are used for coding (i.e. same color for similar information), the number of colors should be limited to 9. Indeed, it corresponds to the maximum number of elements that the human can store in short term memory (7±2 elements; Miller, 1956).

Concerning **which colors** to choose, highly saturated blue should be avoided (associated with disruptions in accommodations, and the central fovea is relatively insensitive to it). Similarly, pure red causes eye difficulties to focus on this color (ISO 15008, 2009). Red-green, blue-yellow, green-blue, and red-blue combinations should be avoided (confusing for color-blind people; Campbell et al., 1997; Stevens et al., 2002). Specific colors intended to coding are detailed in a further section (2.1).

Concerning the **background color** of visual displays, colors with high saturation (and bright white) should be avoided (ISO 9241-12, 1998). In generic guidelines (non-specific to driving), positive polarity (i.e. black characters on white background) seems preferable compared to negative polarity displays (i.e. white on black). A positive polarity would reduce bright to dark eye adaptation, less eye strain, improvement of legibility; however, many people with low vision would prefer negative image polarity (ISO 9241-303, 2008). For a driving environment, the bigger part of light emitted by a positive polarity is a concern for low light driving conditions. The light emitted by displays in a car reduces the dark adaptation of the driver's eyes, and reduces thereby driver's sensitivity to low-contrast objects on the road (Piepenbrock, Mayr, & Buchner, 2014). Therefore, a negative polarity (i.e. light characters on a dark background) is recommended for in-vehicle displays (Green, Levison, Paelke, & Serafin, 1993). A black background seems an appropriate background to display all kinds of symbols colors (ISO 15008, 2009). This color configuration is also valuable to minimize reflections (as recommended by the principle 1.5 of the Japan Automobile Manufacturers Association Guideline [JAMA], 2004).

Besides, it is important to note that the ability to perceive and distinguish colors is leaded by the cone cells in the retina, mediating the central / foveal vision. In low luminosity conditions (e.g. night driving) perception is mainly mediated by other photo receptors: the rod cells (specialized in contrasts and movements). Therefore, colors discrimination is reduced in low luminosity conditions. The peripheral vision (with a degraded visual acuity) is mediated by a high number of rod cells and some cone cells (particularly sensitive to blue wavelength), colors are then badly perceived in peripheral vision except blue (that is why blue is better for large areas and not for text type).

Highlights

- The number of colors simultaneously used should be limited (≈5 max)
- Highly saturated and some colors combination should not be used
- Negative polarity is recommended (i.e. light characters on a dark background)
- Colors are badly perceived in peripheral vision (except blue)

2.2. Text and symbols

The **typeface used** in displays has an impact on text legibility and reading efficiency. In a recent study, Reimer et al. (2014) confirmed that the typeface design in an automotive user interface impacts task completion time and visual demand while driving (e.g. a difference of more than 10% of total glance time was found between two typefaces). In the HARDIE Design Guidelines Handbook, no more than two different fonts and two types of emphasis are recommended (Ross et al., 1996). Ornate typefaces should be avoided (Green, Levison, Paelke, & Serafin, 1993; Ross et al., 1996). Sans serif fonts are recommended (Stevens et al., 2002), particularly in case of quick reading under adverse conditions (e.g. poor lighting; US Department of Defense, 2012). Although fonts with serif may be preferred for continuous reading, it is not the case for isolated words, labels and short messages (Ross et al., 1996). Text effects are also not recommended (e.g. italic, light, bold, condensed, outlines, shading or shadow effects) due to their negative impact on legibility (Ross et al., 1996). Left justify is recommended for texts in fields, and right justify for numbers when they are alone (Green, Levison, Paelke, & Serafin, 1993).

Concerning the **size of characters**, the minimum should be 16’ of arc, with a recommendation of 20’ to 22’ of arc (ISO 9241-303, 2008). At a distance of 70 cm, it would represent a minimum of 3mm and a recommended height of 5mm. For reading while driving, another guideline suggests a 6mm letter height for a driver-display distance of 60 cm (Ross et al., 1996), corresponding to 34’ of arc.

The **use of symbols** and icons is recommended (Ross et al., 1996). Among other advantages, Ells and Dewar (1979, cited in Ross et al., 1996) highlighted that drivers react faster to symbols than to text in an on-road study, and particularly under visually degraded conditions. Another clear advantage is the gain of understanding; this point is addressed in a further section (2.3). Research reported that a combination of text and symbol produced better performance than each one presented alone (Baber & Wankling, 1992; Coury & Pietras, 1989). For symbols, a maximum of four symbol sizes should be used (Ross et al., 1996). Key symbols size would be 30’ of arc (i.e. height of 6mm at 70cm), 20’ of arc for critical symbols (i.e. height of 4mm at 70cm), and 16’ of arc for non-critical symbols (i.e. height of 3mm at 70cm; ISO 9241-303, 2008).

Highlights

- No more than two different fonts and two types of emphasis are recommended
- Sans serif fonts are recommended
- A letter height of 6mm is recommended for a driver-display distance of 60 cm
- A combination of text and symbol improve understanding

2.3. Logic of interaction

One of the goals while designing a new interface is to **maximize attention to the driving task**. Some guidelines recommend that the total glance time to a display while driving between the start and completion of operation task shall not exceed 8 seconds (JAMA, 2004). The task completion should require no more than 20 seconds of total glance time to task displays and controls (JAMA, 2004). The maximum single glance duration recommended is 1.5 seconds (Wierwille, 1993; cited in Stevens et al., 2002; 2 seconds recommended by the JAMA, 2004). When defining the logic of interaction, guidelines recommend that long interaction sequences should be interruptible at any moment without consequences (Stevens et al., 2002). To maximize attention to the driving task, some functionality could be inaccessible while driving (JAMA, 2004; National Highway Traffic Safety Administration [NHTSA], 2012; Stevens et al., 2002). For example, automatic scrolling text should be avoided, because it requires many visual and attentional resources (NHTSA, 2012). The interaction should also be **compatible with the context of use** (ISO 9241-210, 2010). The consideration of parameters such as driver expertise, road environment and traffic condition can influence the type of interaction to choose.

To improve the **learnability** and **memorability** of the interaction, one of the heuristics of Nielsen (2012) is ’Recognition rather than recall’. To avoid that the user have to remember information from one part of the interface to another, instructions for use of the system should be visible or easily retrievable whenever appropriate (Nielsen, 2012). Interaction **efficiency** can also be influenced by system latency. Guidelines recommend a latency inferior to 250ms between driver input and system response (e.g. feedback, confirmation; Stevens et al., 2002). A balance between the breadth and height of menus is recommended (with a number of choices limited to three or four options to minimize the complexity and interaction time; Stevens et al., 2002).

Guidelines recommend to consider driver **errors** while defining the logic of interaction, and to promote an easy recovering of driver errors (ISO 9241-210, 2010). For example, conform to direction-of-motion stereotypes can avoid actuation errors (SAE J1139, 2010; see details in the section 4.2). Information should be presented to the driver about current status, and any malfunction within the system that is likely to have an impact on safety (Commission of the European Communities [ESOP], 2007). Similarly, the user should be able to hear or see immediately if they have made an input error or incompatible choice (Stevens et al., 2002).

Highlights

- Long interaction sequences should be interruptible at any moment without consequences
- A latency inferior to 250ms is recommended
- Information should be presented to the driver about current status

3. Presentation of information and controls

3.1. Coding

When similar information is displayed, different types of coding are used to help the driver to memorize and understand the purpose of the information.

Location coding improves visual identification (and non-visual identification for controls; Stevens et al., 2002). A maximum of 9 different locations is recommended (Ross et al., 1996). In complement, **size** coding can be used. For controls, different sizes can be used to discriminate controls. On a stalk, size coding is most effective if the diameter of the outermost control is 1.27 cm larger than the next–closest control (Campbell et al., 1997).

Shape coding can be used to distinguish different classes of information (e.g. triangles symbols for critical information). The geometrical shapes should be easy to distinguish, which means that their number should be limited (ISO 9241-303, 2008). For controls, the shape of the control (e.g. can help to avoid errors in the driver's hand position by the feel of the control; Campbell et al., 1997).

Luminance and **blink** can be used for coding information. Two displayed information could differ in display luminance at a ratio of at least 1.5:1(ISO 9241-303, 2008). Blink coding can be used to attract attention. A single blink frequency of from 1 Hz to 3 Hz, with a duty cycle of 50 % is recommended (people with photosensitive epilepsy can be affected by a frequency over 3 Hz). Where readability is required during blinking, a blink rate of 0.33 Hz to 1 Hz with a duty cycle of 70 % is recommended (ISO 9241-303, 2008).

Color coding is widely used. Users stereotypes for color should be respected; i.e. green for 'ok, safe condition, or proceed' condition, yellow for 'caution, or risk of danger' conditions, red for 'hazard, prohibition, or stop' conditions, and blue for 'mandatory action, or additional information' conditions (Campbell et al., 1997; ISO 9241-12, 1998; Ross et al., 1996). Guidelines recommend that this should not be the only mean of coding (because 8 % to 10 % of the male population is color-blind) but in complement to another coding form (i.e. redundancy in coding; Campbell et al., 1997; ISO 9241-303, 2008).

Highlights

- Coding helps understanding and memorization
- Location, size, shape, luminance, blink and color can be used for coding
- Green, yellow, red and blue have specific meaning
- Color should not be the only mean of coding

3.2. Prioritization

Four criteria are cited to prioritize information and controls: relevance for the primary driving task, criticality, urgency and frequency of use (Stevens et al., 2002).

Information and controls **relevant to driving** have to be prioritized during HMI design (Green et al., 1993; Stevens et al., 2002). Other information should not adversely interfere with displays or controls required for the primary driving task (ESOP, 2007).

The **criticality** defines the severity of the consequences if the information is not acted upon (Campbell et al., 1997; ESOP, 2007). For example, radio tuning is a high distraction source described in the crash record and has then established safety-relevance (e.g. Stutts, et al, 2001, cited in Alliance of Automobile Manufacturers [AAM], 2006).

The **urgency** defines the rapidity needed for reaction (Campbell et al., 1997). For example, audible horn and windscreen washer are functions which are used in a short time. Those functions have to be prioritized in terms of location and display layout (Green et al., 1993).

Frequently used controls should be closer to the driver than others (ESOP, 2007; Green et al., 1993; Turner and Green, 1987). However, few data is available in guidelines and human-factors literature on controls frequency of use.

The SAE J1138 Report (2009) proposes high priority driver hand controls (e.g. audible horn, audio controls, climate controls, hazard flasher, etc.). For prioritized functions, reachability and detectability shall be given a higher weight when it comes to positioning of controls and information. Prioritized information should be presented higher and closer to the normal line of sight to reduce visual transition and accommodation (Stevens et al., 2002). High priority controls should be closer to the driver, easy to reach and operate (Turner & Green, 1987; Stevens et al., 2002). Green et al. (1993) suggest that prioritized controls should be close to common locations of the hands, and easy to reach from the steering wheel hand position (e.g. mounted on the steering wheel, on pods, or on the eye brow of the instrument panel).

Highlights

- Prioritization could be made according 4 axis: relevancy for driving, criticality, urgency, and frequency of use
- Prioritized information should be presented higher and closer to the normal line of sight to reduce visual transition and accommodation
- High priority controls should be closer to the driver, easy to reach and operate

3.3. Familiarity, consistency, regulation and standards

In order to promote HMI usability, guidelines recommend that controls and displays should be consistent with users' expectations (Green et al., 1993). Expectations depend on users' past experiences (with the system or similar systems), on commonly accepted conventions, but also on individual differences (e.g. level of knowledge, culture, gender; Stevens et al., 2002). Inconsistent systems (not matching driver expectations) would be more difficult to use, cause more errors, and would take more time to be learned (Stevens et al., 2002).

Consistency with similar interfaces should then be respected. Presentation of information and controls should be coherent between same brand products, but should also consider other brands products (i.e. industry standards) to be consistent with drivers' experiences. For Multi-Purpose Vehicles (MPV), an analysis of industry standards was led on the main controls (Appendix 1). Industry standards are addressed in a further section (4.1). Moreover, between displays of a vehicle, consistency has to be respected for message terminology, color coding, interaction modes, labels, icons, etc. (Stevens et al., 2002; Turner & Green, 1987). Similarly for information presentation, it is recommended to support driver's mental model of reality (e.g. fuel gauge represented vertically; Ross et al., 1996). With regard to controls, switches with similar responses (such as turning a function on) should have similar modes of operation (Green et al., 1993). On the contrary, objects and information that look the same should act the same (Campbell et al., 1997). However, this criterion has to be balanced with **distinctiveness** to avoid errors and facilitate perception and processing. For example, it is recommended to avoid similar appearance between climate control and radio (SAE J1138, 2009).

Internationally or nationally agreed **standards** should be used for icons, pictograms, acronyms, abbreviations, etc. (ESOP, 2007). Some tell-tales and indicators are defined in regulation (Regulation No. 121, United Nations Economic Commission for Europe [UNECE], 2011), in complement, standards are available (ISO 2575, 2010). Symbols are particularly useful to gain understanding when the driver does not understand well than language of the system.

Expectancies are also modulated by **culture**. For example, a study of McGrath (1974; cited in Turner & Green, 1987) reported control expectancies from different cultures through a survey. Americans tended to expect panel-mounted controls while Europeans were more used to stalk controls (especially French and Italians for the headlight switch, and the French and British for the horn).

Highlights

- Controls and displays should be consistent with users' expectations
- Consistency with similar interfaces should be respected
- Consistency with mental models should be respected
- Objects and information that look the same should act the same
- Standards should be used for icons, pictograms, acronyms, abbreviations, etc.

4. Layout of controls and information

4.1. Density and clutter

Interface layout should help the drivers to direct their attention to the relevant information, encourage an easy understanding, and an easy response to that information. Besides grouping, displays should therefore be simple in overall density and local density (Stevens et al., 2002). **High information density may cause overload** and increase errors and difficulties in finding appropriate information.

Blank space is recommended to provide structure in a visual interface (Stevens et al., 2002). A balanced screen layout is suggested with plenty of 'white space' around information groups (at least 50% 'white' space for text screens). Similarly, these guidelines recommend keeping backgrounds simple and muted (BSI, 1996; cited in Stevens et al., 2002; ESOP, 2007).

Displays should **not contain irrelevant information** or rarely needed. Indeed, non-relevant information competes with relevant information as distractors during visual search (Stevens et al., 2002). Information that the driver needs to read should be minimized (Green et al., 1993). Campbell et al. (1997) define text messages complexity in terms of information units, i.e. one information unit correspond to one key noun or adjective contained within a message. A text messages should contain a maximum of 4 information units when the vehicle is in motion in order to minimize the eyes–off–road time (Campbell et al., 1997). They also reports that a message with a high complexity is composed of more than 9 information units (the processing time would exceed 5 seconds), and a low complexity message would be composed of 3 to 5 information units.

4.2. Grouping

The layout of controls and information is critical for HMI interaction quality. Displays should be well structured, and related information should be coded so that it can be perceived as such (Ross et al., 1996; Stevens et al., 2002). Groups of controls or information should be visually distinct '**chunks**' to increase visual search efficiency. The number of groups should be minimized (ISO 9241-12, 1998), the number of 7±2 groups is recommended (corresponds to the short term memory span; Miller, 1956).

Perceptual grouping relies on the Gestalt Law of perception (Ross et al., 1996). The law of proximity implies that elements spatially close are perceived as belonging to each other. The law of similarity implies that elements are perceived as belonging together if they are similar (see section 2.1 for more information on the coding of information and controls). The law of closure implies that non-existent parts of a figure are completed automatically. Other means can be used to improve visual perception of grouping (e.g. box around the groups; ISO 9241-12, 1998).

Controls and information should be grouped by **sequence of use**. If a task requires a specific sequence, information and controls should be grouped and placed in an order which supports that sequence (Green et al., 1993; ISO 9241-12, 1998; Turner and Green, 1987). Similarly, **frequency of use** can be used to determine the layout of controls. However, as suggested above, few data is available on controls and information real frequency of use. **Functional grouping** is mostly used if the task does not require a specific sequence (i.e. groups that are semantically related and meaningful to the user; SAE J1138, 2009; ISO 9241-12, 1998). Guidelines also recommend to group information with their related controls (Stevens et al., 2002).

Highlights

- The number of chunks should be minimized (max. 7±2)
- Groups of controls and information could be made according: sequence of use, frequency of use, functional grouping
- Information should be close to their related controls

4.3. Spatial positioning

4.3.1. Controls

Guidelines recommend being consistent with drivers' expectations in terms of positioning across product lines (ISO 9241-12, 2008; Turner & Green, 1987). The 'transference' of past knowledge from previous experiences contributes to the construction of drivers mental models of the interface operating. Be consistent with **industry standards** and familiar implementations is then recommended. For each controls and each truck targeted currently for sale (MPV range), spatial positioning is detailed in appendix.

Spatial positioning standards recommended in guidelines are detailed in Table 1.

Table 1. Spatial positioning standards recommended in guidelines. The reference plane is a vertical longitudinal plane through the steering wheel center.

Control	Location	Source
Master lighting control	Left of reference plane	SAE J1138, 2009 ISO 4040, 2010
	Left panel	Turner & Green, 1987
Headlamp beam switching	Left plane behind the steering wheel	ISO 4040, 2010
Headlamp Dimmer	Left of reference plane	SAE J1138, 2009
Headlamp Flasher	Left of reference plane	SAE J1138, 2009
	Left plane behind the steering wheel	ISO 4040, 2010
Turn Signal	Left of reference plane	SAE J1138, 2009
	Left plane behind the steering wheel	ISO 4040, 2010
Power Door Lock	Left of reference plane	SAE J1138, 2009
Power Mirror	Left of reference plane	SAE J1138, 2009
Power Windows	Left of reference plane	SAE J1138, 2009
Audio Controls	Right of reference plane	SAE J1138, 2009
	Right panel Or right side of the steering wheel	Turner & Green, 1987
Climate Controls	Right of reference plane	SAE J1138, 2009
	Right panel	Turner & Green, 1987
Gearshift	Right of reference plane	SAE J1138, 2009
Hand Brake	Right of reference plane	SAE J1138, 2009 ISO 4040, 2010
Telephone	Right of reference plane	SAE J1138, 2009
Windshield Defroster	Right of reference plane	SAE J1138, 2009
	Right panel	Turner & Green, 1987
Audible horn	Center of the steering wheel	SAE J1138, 2009 Turner & Green, 1987
	Left plane behind or center of the steering wheel	ISO 4040, 2010
Hazard flasher	Right of reference plane	SAE J1138, 2009
Windscreen washer and wiper control	Right or left of the reference plane	SAE J1138, 2009 ISO 4040, 2010
	Left reference plane	Turner & Green, 1987
Cruise control	On the steering wheel	Turner & Green, 1987

According to guidelines, some functions can be grouped such as the windscreen washer and wiper controls (ISO 4040, 2010; Turner & Green, 1987), or the optical warning and headlight-beam switching (ISO 4040, 2010). On the contrary, the master light control shall not be operated by the same control as the audible warning, the windscreen wiping, the windscreen washing and the turn signal (ISO 4040, 2010). The retarder control should also be independent from the turn indicator (ISO 4040, 2010).

For the radio, Turner and Green (1987) recommend to avoid push button (e.g. up and down) for manual tuning, whether a knob control (in order to feel the change in force and estimate where the radio has been tuned).

More globally, it is recommended to locate controls close to their associated display (Stevens et al., 2002), and to keep coherence between stimulus and response location. Indeed, reactions are usually more accurate and faster when the stimulus occurs in the same relative location as the response required (called Simon Effect in psychology). An example for in-vehicle interfaces is the recommendation to place the auditory alert of the lane departure warning system on the side of the lane crossed (e.g. Campbell et al., 2007).

Prioritized controls should be positioned closer to the driver than others (e.g. horn and windshield washer quickly reachable; Turner & Green, 1987); more details on prioritization in the section 2.2.

4.3.2. Information

For information display, spatial positioning should **follow reading habits** (in Europe, left to right and top to bottom; Green et al., 1993). Moreover, information at the top and to the left is perceived to be more important (i.e. natural hierarchy; Green et al., 1993). 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; ESOP, 2007; JAMA, 2004; Stevens et al., 2002). Such positioning also maximizes the possibility for the driver to use peripheral vision to monitor the roadway while principally looking at the display.

When text and images are presented, it seems that words would be quicker identified when they are located in user’s right visual field, and images would be identified quicker in the left visual field (Kolb & Whishaw, 2009). This corresponds to hemisphere specialization and help reducing the cognitive load of the user.

Concerning information display elements, Turner and Green (1987) suggest locating radio display at the top of the right panel (because of its frequent use, to minimize how far away from the road the driver must look). Standards recommend that the speedometer should be visible without head movement (ISO 4040, 2010), as well as designated tell-tales and indicators (e.g. critical condition for the engine oil pressure; ISO 4040, 2010).

Highlights

- Controls could be positioned following industry standards
- Information positioning should follow reading habits
- Information at the top and to the left is perceived to be more important

5. Controls characteristics

Some control characteristics such as size, distance between controls, or surface area are not addressed here (outside the scope), but detailed described in guidelines (Campbell et al., 1997; Stevens et al., 2002; US Department of Defense, 2012). Control-displays panels should be labeled, and it is recommended to place labels above items. However, sometimes the uniqueness (e.g. shape) of the control is so widely recognizable that identification labels are not needed (e.g., ignition, if key cylinder; SAE J1138, 2009).

5.1. Control selection

The selection of a control type depends on different criteria (Campbell et al., 1997):

- The nature of the task (e.g. continuous movement, or simply turning a component on or off)
- The nature of the controlled object (e.g. number of position associated, amount of precision required, amount of force required, direction of movement)
- The desired location (e.g. stalk around the steering wheel and push-button on it)
- Discrimination from other controls: discrimination by shape, size, texture (smooth, fluted, knurled but no more than one of each type of texture for discrimination purpose)
- The consequence of driver error

The direction of the control movement should be coherent with the direction of movement of the associated display (Campbell et al., 1997). Similarly, stereotypes are strongest when the orientation and motion of the control correspond to the orientation and motion of the controlled element (e.g. power mirror controls; SAE J1139, 2010). Rotary and slides switches clearly indicate the user can select only one option at a time (Turner & Green, 1987). According to the control function, different control types are recommended (Table 2).

Table 2. Suggested control type for different types of control functions.

Control function	Suggested control type	Source
Selection among two discrete positions (e.g. on/off)	Two–position stalk	Campbell et al., 1997
	Rocker switch	Campbell et al., 1997 Stevens et al., 2002 Green et al., 1993 Turner & Green, 1987
	Push–button	Campbell et al., 1997 Stevens et al., 2002 Green et al., 1993 Turner & Green, 1987
	Toggle switch	Campbell et al., 1997 Stevens et al., 2002
	Slide	Turner & Green, 1987
	Push–pull knob	Campbell et al., 1997 Stevens et al., 2002
Selection among three of more discrete positions (e.g. climate air flow directions)	Multipurpose stalk	Campbell et al., 1997
	Three–position toggle	Campbell et al., 1997
	Push–buttons (for three alternatives only)	Campbell et al., 1997
	Key pad	Campbell et al., 1997
	Touch screen	Campbell et al., 1997
	Slide	Campbell et al., 1997 Stevens et al., 2002 Green et al., 1993 Turner & Green, 1987
	Discrete rotary knob	Campbell et al., 1997 Stevens et al., 2002 Green et al., 1993 Turner & Green, 1987
Continuous precise adjustment (e.g. radio volume)	Continuous rotary knob	Campbell et al., 1997
	Thumbwheel (when readout is required)	Campbell et al., 1997 Stevens et al., 2002
Continuous gross adjustment (e.g. intermittent windshield wiper)	Continuous rotary knob	Campbell et al., 1997
	Lever	Campbell et al., 1997
	Touch screen	Campbell et al., 1997
Large force application (e.g. column tilt)	Lever	Campbell et al., 1997

Some operation recommendations are addressed in the SAE J1139 guideline (2010):

- For windows lift, rockers (arranged in a 2*2 and not 1*4 configuration) or push-pull buttons can be used (push to the bottom to lower the window).
- For the turn signal, the left stalk should be raided and low.
- For the wipers, the left stalk should be rotated over the top or raised.
- Finally, when headlights are on a stalk, rotating over the top should turn on the headlamps and pulling the stalk should turn the high beam on.

5.2. Affordance of control

A control is affordable when its qualities or properties define its possible uses or make clear how it can or should be used. Affordances rely on user mental models and guidelines strongly recommend following this standards to promote usability (Stevens et al., 2002; Turner & Green, 1987). Standards are reported in Table 3.

Table 3. Suggested control movement for different types of control functions.

Control function	Suggested control movement	Source
On	Up	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Forward	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Right	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Pull	SAE J1139, 2010 Campbell et al., 1997
	Rotate over the top (stalk) Or Turning clockwise	SAE J1139, 2010 Stevens et al., 2002
Right	Turning clockwise	Stevens et al., 2002 Campbell et al., 1997
	Right	Campbell et al., 1997
Up	Up	Campbell et al., 1997
	Rearward	Campbell et al., 1997
Increase	Up	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Forward	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Right	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997
	Pull	SAE J1139, 2010
	Rotate over the top (stalk) Or Turning clockwise	SAE J1139, 2010 Stevens et al., 2002 Campbell et al., 1997
	Up	SAE J1139, 2010 Turner & Green, 1987 Campbell et al., 1997

Highlights

- Controls characteristics should be chosen according to different criteria
- In consistency with standard and drivers' mental models, some properties of controls induce affordances

Conclusion

This document gathered existing technical literature, in which guidelines or recommendations were presented in order to promote usability while designing in-vehicle HMI. The goal is to reduce initial and running costs and to increase functional performance and sustainability of the HMI at the beginning of concepts design. Further studies have to be performed to complement these recommendations with data collected on trucks. Moreover, advancements in display technologies are now making it possible for interface designers to explore information and controls designs that are radically different from the conventional mechanical dashboards. With such rapidly changing in-vehicle interfaces, it is becoming important to consider human factors to avoid complex and difficult to use HMI that could be detrimental for road safety.

References

Reference	Motor vehicles specific	Considering commercial vehicles
Alliance of Automobile Manufacturers. (2006). *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems*. Washington, DC: Alliance of Automobile Manufactures.	X	X
Baber, C., & Wankling, J. (1992). An experimental comparison of test and symbols for in-car reconfigurable displays. *Applied Ergonomics*, *23*(4), 255-262.	X	
Bedinger, M., Walker, G. H., Piecyk, M., & Greening, P. (2015). 21st century trucking: A trajectory for ergonomics and road freight. *Applied Ergonomics, 53*, 343–356.	X	X
Campbell, J.L., Carney, C., and Kantowitz, B. H. (1997). *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO).* Technical Report FHWA-RD-98-057.	X	X
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*.	X	X
Coury, B. G., & Pietras, C. M. (1989). Alphanumeric and graphic displays for dynamic process monitoring and control. *Ergonomics*, *32*(11), 1373-1389.		
Dozza, M. (2013). What factors influence drivers' response time for evasive maneuvers in real traffic?. *Accident Analysis & Prevention, 58*, 299-308.	X	X
Green, P., Levison, W., Paelke, G., & Serafin, C. (1993). *UMTRI - Suggested Human Factors Design Guidelines for Driver Information Systems*. UMTRI Report.	X	
International Organization for Standardization. (2009). *ISO 15008 - Road vehicles – Ergonomic aspects of transport information and control systems – Specifications and test procedures for in-vehicle visual presentation.* International Organization for Standardization.	X	X
International Organization for Standardization. (2010). *ISO 2575 - Road vehicles—Symbols for controls, indicators and tell-tales.* International Organization for Standardization.	X	X
International Organization for Standardization. (2008). *ISO 9241-303 - Ergonomics of human-system interaction - Requirements for electronic visual displays.* International Organization for Standardization.		
International Organization for Standardization. (2010). *ISO 9241-210 - Ergonomics of human-system interaction – Human-centred design for interactive systems*. International Organization for Standardization.		
International Organization for Standardization. (1998). *ISO 9241-12 - Ergonomic requirements for office work with visual display terminals (VDTs) – Presentation of information.* International Organization for		

Standardization.		
International Organization for Standardization. (2001). *ISO 4040 - Road vehicles—Location of hand controls, indicators and tell-tales in motor vehicles*. International Organization for Standardization.	X	X
Japan Automobile Manufacturers Association. (2004). *Guideline for in-vehicle display systems, version 3.0*. Japan Automobile Manufacturers Association.	X	X
Kolb, B., & Whishaw, I. Q. (2009). *Fundamentals of human neuropsychology*. Macmillan.		
Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological review, 63*(2), 81.		
National Highway Traffic Safety Administration. (2012). Visual-manual NHTSA driver distraction guidelines for in-vehicle electronic devices. *Washington, DC: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT)*.		
Nielsen, J. (2012). *Usability 101: Introduction to Usability*. Nielsen Norman Group. Retrieved from https://www.nngroup.com/articles/usability-101-introduction-to-usability/		
Piepenbrock, C., Mayr, S., & Buchner, A. (2014). Smaller pupil size and better proofreading performance with positive than with negative polarity displays. *Ergonomics, 57*(11), 1670-1677.		
Reimer, B., Mehler, B., Dobres, J., Coughlin, J. F., Matteson, S., Gould, D., Levantovsky, V. (2014). Assessing the impact of typeface design in a text-rich automotive user interface. *Ergonomics*, 1–16.	X	
Ross, T., Midtland, K., Fuchs, M., Pauzie, A., Engert, A., Duncan, B., Vaughan, G., Vernet, M., Peters, H., Burnett, G., and May, A. (1996). HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by ATT Systems.	X	X
SAE. (2010). *J1139 - Direction-of-Motion Stereotypes for Automotive Hand Controls*. SAE.	X	X
SAE. (2009). *J1138 - Design Criteria - Driver Hand Controls Location for Passenger Cars, Multipurpose Passenger Vehicles, and Trucks (10 000 GVW and Under)*. SAE.	X	X
Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). *TRL - Design guidelines for safety of in-vehicle information systems*. TRL.	X	X
Turner, C. H., & Green, P. (1987). *Human Factors Research on Automobile Secondary Controls: A Literature Review*. Technical Report UMTRI-87-20.	X	
United Nations Economic Commission for Europe (UNECE). (2011). *Regulation No. 121 - Identification of controls, tell-tales and indicators*, (March 1958), 1–19.	X	X
US Department of Defense. (2012). MIL-STD-1472G - Design Criteria Standard - Human Engineering, (August).	X	X

Appendices

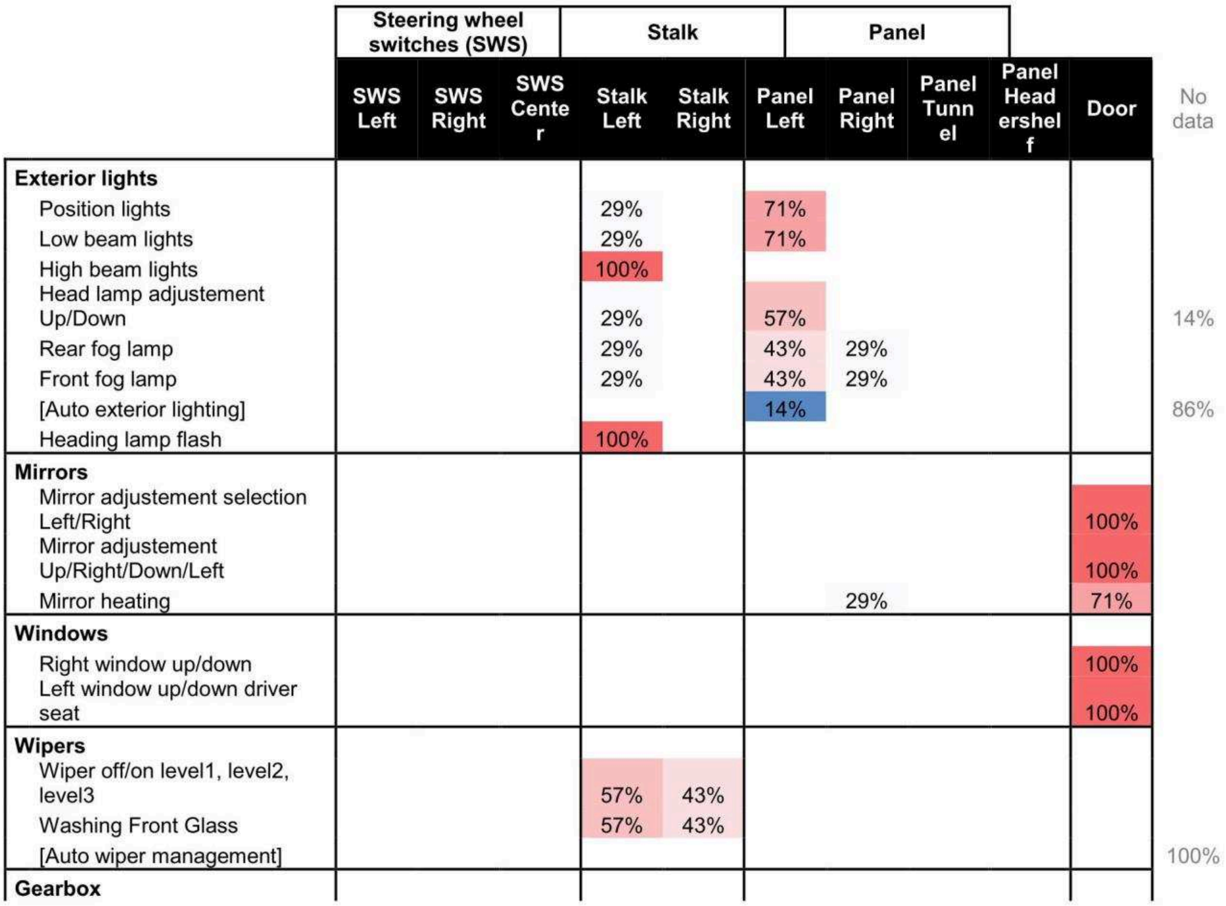
Appendix 1 : Industry standards for the MPV range

The data collection was conducted from internet searches and existing internal documents. The analysis focuses on MPV vehicles currently for sale (October 2015):

- Scania, P-Serie (2013-present)
- Mercedes, Atego (2013-present)
- Volvo, FL-FE (2013-present)
- MAN, TGL (2013-present)
- DAF, LF (2013-present)
- Iveco, New Eurocargo (2015-present)
- Renault Trucks, D – DWide – C250-320ch (2013-present)

Limitations to consider:

- Uncertainty and missing information due to the difficulty to collect source documents (with full HMI description),
- Not exhaustive at all (no consideration of all vehicles options),
- No description of some MPV competitors: Mercedes Antos and DAF CF (driver interface similar to HD Range).



	Steering wheel switches (SWS)			Stalk		Panel					
	SWS Left	**SWS Right**	**SWS Center**	**Stalk Left**	**Stalk Right**	**Panel Left**	**Panel Right**	**Panel Tunnel**	**Panel Headershelf**	**Door**	No data
Exterior lights											
Position lights				29%		71%					
Low beam lights				29%		71%					
High beam lights				100%							
Head lamp adjustement Up/Down				29%		57%					14%
Rear fog lamp				29%		43%	29%				
Front fog lamp				29%		43%	29%				
[Auto exterior lighting]						14%					86%
Heading lamp flash				100%							
Mirrors											
Mirror adjustement selection Left/Right										100%	
Mirror adjustement Up/Right/Down/Left										100%	
Mirror heating							29%			71%	
Windows											
Right window up/down										100%	
Left window up/down driver seat										100%	
Wipers											
Wiper off/on level1, level2, level3				57%	43%						
Washing Front Glass				57%	43%						
[Auto wiper management]											100%
Gearbox											

	Steering wheel switches (SWS)			Stalk		Panel					
	SWS Left	**SWS Right**	**SWS Center**	**Stalk Left**	**Stalk Right**	**Panel Left**	**Panel Right**	**Panel Tunnel**	**Panel Headershelf**	**Door**	No data
Drive					57%		14%	29%			
Neutral					57%		14%	29%			
Reverse / Crawl					57%		14%	29%			
Auto/Manual selector					71%			14%			14%
Gear Up/Down					86%			14%			
Climate											
Temperature Up/Down							100%				
Air flow setting Up/Down/Front							100%				
Air flow adjustement off/on level							100%				
Recycling air flow							100%				
Air conditioning							100%				
[Automatic air flow]							29%				71%
Heating glass							100%				
Parking heater							43%	43%	14%		
Eco climate							29%				71%
Radio and phone											
Volume Up/Down	71%				14%		57%		29%		
Mute					14%				14%		71%
Previous/Next	57%				14%		57%		29%		
Source	14%				14%		57%		29%		
Tuner scan					14%		57%		29%		
[Repeat]							29%		29%		43%
[Random]							29%		29%		43%
Memo1,2,3,4,5,6							71%		29%		
[Radio menu]					14%		57%		29%		
Phone Up/Down	29%	43%			14%		14%		29%		
Driving modes											
Driving mode selection (ASL, CC, ACC)		43%			14%	14%					29%
Cruise control set		29%									71%
Cruise control Up/Down		71%	14%		14%						
Cruise control resume	29%	43%	14%		14%						
Cruise control 0	14%	43%	14%		14%						14%
Cruise control off	14%					14%					71%
[Time gap Up/Down]			14%								86%
[SpeedMemo]											100%
[Regeneration]											
Regeneration activation							71%				29%
Auto regeneration											100%
Regeneration inhibition							71%				29%
Driving functions											
Right/left turn indicator				100%							
Horn			29%	71%							
Retarder		14%		29%	57%						
Park brake							29%	71%			
Cluster											
Down/Up	29%		14%		29%		14%				14%
Left/Right	14%		14%					14%			57%
OK	29%	14%			29%		14%	14%			14%
Exit	14%	14%			29%		14%	14%			29%
Black panel						14%					86%
Brighteness adjustment						14%	14%				71%
Vehicles settings											
Auto/Manu retarder							43%				57%

	Steering wheel switches (SWS)			Stalk		Panel					
	SWS Left	SWS Right	SWS Center	Stalk Left	Stalk Right	Panel Left	Panel Right	Panel Tunnel	Panel Headershelf	Door	No data
Engine Speed control Up/Down		29%					29%				43%
Engine Speed control On/Off		14%					29%				57%
Hazard warning						14%	86%				
[Camera]							29%	14%			57%
[Navigation]							43%	14%			43%
Sunvisor							14%				86%
Front wheel differential lock							86%				14%
Rear inter axle/ wheel differential lock							86%				14%
Rear inter axle differential lock							86%				14%
Rear wheel differential lock						14%	86%				
PTO1							86%				14%
PTO2							86%				14%
Beacon warning lamp						14%	43%				43%
Panic alarm							29%				71%
Muddy site							43%				57%
Hill start aid							100%				
Auto neutral							29%				71%
Off road							14%				86%
ASR off road							71%				29%
Boogie lift selector up/auto/down						29%	29%				43%
Boogie ratio control							29%				71%
ADR main switch						29%	29%				43%
Air suspensions up/down						43%					57%
Air suspensions mem/rec						29%					71%
Air suspensions driving level control						29%					71%
Tail lift						29%	14%				57%
Emergency call						29%					71%
Rear work projector lamp						57%	29%				14%
Equipment light					14%	43%	29%				14%
Acoustic reverse warning							71%		29%		
Reduce set burglar alarm									29%		71%
Sunroof control							14%		43%		43%
AEBS inhibit							43%				57%
LDWS inhibit							71%				29%
Comfort settings											
[Interior light]							57%		14%		29%
Steering wheel Lock/Unlock						86%	14%				
Lock							14%		29%	29%	29%
Tachograph											
Tachograph									100%		

2.2. Provide human-factors guidelines on speedometer design

As mentioned above, experts rely on ergonomic recommendations to ensure that their concepts consider human capabilities and limitations. In this sense, the review of the existing guidelines is extensive, but not exhaustive. For example, one of the major elements of the instrument clusters is the speedometer, with a high frequency of use. Nevertheless, the existing literature did not allow to conclude which speedometer type is better for truck driving on a screen instrument cluster from an ergonomic point of view. This input was important for experts in user-centered design, therefore, two studies were conducted (Papers II and III).

2.2.1. Objectives

The speedometer is an essential part of instrument clusters. Its design is crucial for road safety. However, the existing literature does not draw conclusions as to which speedometer type is better for truck driving. A digital speedometer would be more beneficial when obtaining absolute and relative readings, while an analogue speedometer would be more efficient and less distracting when detecting dynamic speed changes.

2.2.2. Method

In a first study, the usability and distraction of a digital speedometer and an analogue speedometer were compared in simulated truck driving. The objective was to confirm if the results presented in the literature were applicable on screen instrument cluster for truck driving.

Based on this study, a second experiment assessed and compared both types of speedometer against a redundant speedometer (which simultaneously present digital and analogue speedometers). Efficiency, usability and visual distraction measures were collected for all three types of speedometers in a simulated truck driving setting.

2.2.3. Highlights and application

The digital speedometer was more beneficial when obtaining absolute and relative readings, while the analogue speedometer was more efficient and less distracting when detecting dynamic speed changes. The redundant speedometer combined the benefits of each type presented separately.

This result was applied by HMI experts in the following user-centered design process (display of a redundant speedometer).

Paper II

Analogue versus digital speedometer: effects on Distraction and Usability for Truck Driving

François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2016). Analogue versus digital speedometer: effects on Distraction and Usability for Truck Driving. In Morris, A., Mendoza, L. (Eds.). Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems, Loughborough, UK, June 30st - July 1st 2016 (p. 18-25). Lyon: Humanist Publications.

ANALOGUE VERSUS DIGITAL SPEEDOMETER: EFFECTS ON DISTRACTION AND USABILITY FOR TRUCK DRIVING

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ABSTRACT: The instrument cluster in the trucks become screens and this brings new challenges for the speedometer design. Both traditional speedometers (i.e. analogue and digital) present design advantages. However, the existing human-factors literature does not allow concluding whether one or the other type is more usable and less distracting. Digital speedometers would be more appropriate for absolute and relative reading, while analogue speedometers would be more efficient and less distracting for detecting dynamic speed change. This study compared both speedometer types on a screen instrument cluster in simulated truck driving. The task-dependant results were replicated. This study updates previous literature and provides a basis to investigate other speedometer types which would be efficient on the three tasks.

1 INTRODUCTION

During driving, drivers interact with the speedometer in a monitoring way for different purposes: maintain vehicle speed within desired safety margins, follow speed limit signs, carry out necessary adjustments (acceleration or deceleration), in overtaking situations, or in any driving environment in which speed plays a major role. Speedometer design has critical implications for road safety. Speedometer frequency of usage is high and the off-road glances associated could overlap with a time critical event [1]. Recarte and Nunes (2002) stressed that speedometer visual inspection increases in a restricted-speed road environment [2]. Truck drivers spend much time on the road in a professional context (up to 56h in any given work week) [3], and speed has become a particular concern for them due to the strengthening of the regulation and road controls. Moreover, even if trucks drivers are experts, human error accounts for 90% of trucks accidents [4]. A misjudgement of speed can lead to rollover in a bend (particularly for concrete mixer trucks), jackknifing at braking, or swinging out on slippery roads [4]. For those reasons, it is essential to carry out the speedometer design with the following objectives: provide accurate speed information in a quick way (i.e. minimize eyes off-road time), and avoid unnecessary mental workload increase (i.e. information easy to understand and interpret).

Two main speedometers types are currently proposed in the truck industry: analogue (i.e. moving indicator along a scale) and digital speedometers (i.e. digits). In the human factors literature, some studies investigated the effects of both speedometers on human behaviour. Results are not clear and it seems that the more appropriate mean of presenting the speed information to the driver depends on the task performed. A digital speedometer would be more appropriate for an absolute reading of the speed value [5–8], and for a relative reading task (i.e. compare to a target speed) [5, 9], while an analogue speedometer would be better for reading a dynamic speed change [9–11].

However, updating these studies could be beneficial for trucks' HMI designers. Indeed, most studies are dated and have been conducted on cars. Compared to car driving, truck drivers' eye position is higher and farther from the dashboard. Differences in terms of vehicle speed variation (due to vehicle weight) and criticality could impact speed management and control. We also can assume different results due to social changes (i.e. different relation to speed), technology changes (i.e. the expansion of digital formats in the everyday life), and speedometer context of use (e.g. drivers need now accuracy when choosing a cruise control target speed). Moreover, existing studies have been obtained with conventional mechanical and physical supports. Advancements in display technologies with screens as instrument clusters make it interesting to update the results for a contemporary and realistic view.

The objective of this study is to compare an analogue and a digital speedometer in simulated truck driving in terms of usability and distraction. As mentioned above, the literature indicates that both displays present benefits depending on the task tested. This study aims to confirm if those results are applicable on screen instrument cluster for truck driving.

2 PARTICIPANTS

18 men trucks drivers (42 years±7.2) took part in the experiment. Most participants drove a truck several times a month (33% less than once a month). All participants held valid truck licences and reported normal or corrected-to-normal vision and audition. In their cars, 55% of the participants used an analogue speedometer (39% use a digital one). For truck driving, most participants drove with a digital speedometer (94%, all in Renault Trucks). Written informed consents from each participants were obtained.

3 MATERIALS

The analogue speedometer was composed of a semi-circular fixed scale graduated inside and marked outside all 10 km/h between 0 and 120 km/h (Fig. 1a). The moving pointer was a non-complete needle pointing the scale attached to the scale. The digital speedometer was a 2 digits display with a refresh rate of 1.25Hz (Fig. 1b). Both speedometers were centred in upper half of an 8” screen in place of the instrument cluster. Decision on the graphic characteristics of the two speedometers have been taken considering existing fully reconfigurable clusters in cars (e.g. the needle is often cut off to display something inside), and the existing human factors knowledge (e.g. scale marked in numbers multiples of 10) [7].

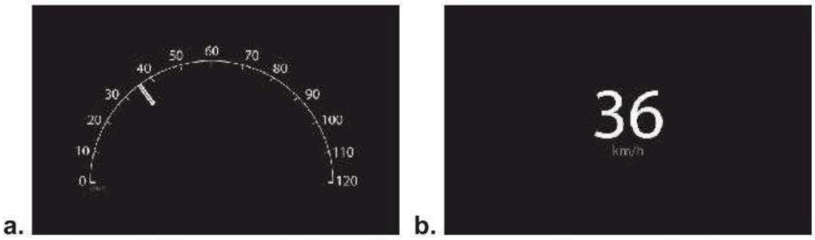

Figure 1. Representation of the two speedometer displays.
a. Analogue speedometer;
b. Digital speedometer

Three tasks were asked to participants. For the task 1, drivers were required to report the speed (e.g. speed value displayed: 49; answer: ‘49’). For the task 2, drivers were asked to say if the speed value displayed is under or over 50 km/h (e.g. speed value displayed: 49; answer: ‘minus’). For the task 3, drivers were asked to say if the speed displayed was increasing or decreasing (e.g. speed displayed: from 30 to 49 km/h; answer: ‘acceleration’). 12 stimuli were presented for each speedometer type and for each task.

4 PROCEDURE

Before the experimental phase, participants were informed of the details of the study and signed a consent form. Afterwards, the head-mounted eye tracking device was positioned and calibrated (monocular Ergoneers Dikablis Essential, 50Hz). Participants were given a 5 min familiarisation with both speedometers displays. Before each session, participants read the instructions and performed 4 training trials (to ensure the comprehension of the task).

During the experiment, participants drove on a fixed-base medium-fidelity truck driving simulator. They were required to follow a red car on a highway. The information cluster remained black most of the time. Every 8 to 12s (randomly) a sound announced that the speedometer was about to be displayed. Thus the driver could give his answer aloud (that would remove the display). The test was composed of 6 sessions, corresponding to the 3 tasks for the 2 speedometers displays. A cognitive distraction questionnaire was proposed after each driving session.

At the end of the study, participants were asked to report their preferences (order of preference and satisfaction score). Each participant was tested individually and experienced all conditions. The order of the experimental condition presentation were counterbalanced following three Latin squares, and stimuli presentation was randomly arranged for each session. The total test duration was about an hour and a half.

5 RESULTS AND DISCUSSION

Cognitive distraction was self-reported thank to the Rating Scale Mental Effort [12]. Scores between 0 and 150 were acquired after each session in order to evaluate the effects of the speedometer and the task. Scores were analysed using non-parametric Friedman and Wilcoxon tests for paired samples. Visual distraction was analysed through the total glance time away from road (from stimulus display to stimulus disappearance). 2×3 repeated-measures ANOVAs and Tukey HSD post-hoc tests were performed on corrected means. Values apart from the mean value minus or plus two standard deviations were discarded from the data analysis. Regarding usability measures, efficiency was assessed through task completion times (from stimulus display to driver's answer) and accuracy (driver's answer with the real value displayed). After the three driving sessions with one speedometer type, global usability was examined through a five items questionnaire (5 points Likert scales) corresponding to the five aspects of usability defined by Nielsen (i.e. learnability, efficiency, memorability, errors and satisfaction)[13]. Finally, driver preference was acquired at the end of the experiment (order of preference and satisfaction score between 0 and 10). 2×3 repeated-measures ANOVAs and Tukey HSD post-hoc tests were performed on task completion times. Friedman and Wilcoxon tests were computed on accuracy, usability and satisfaction scores.

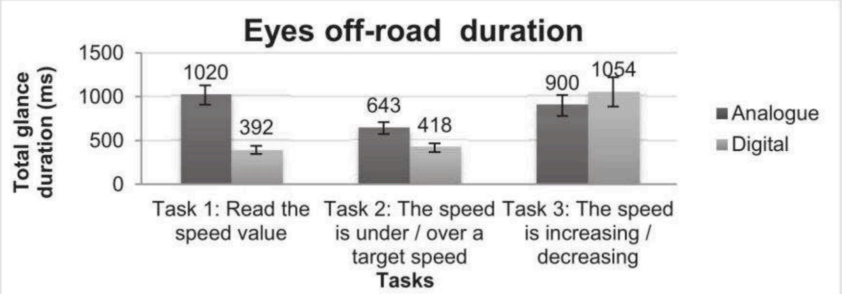

Figure 2. Total off-road glance duration in milliseconds (with standard deviation) for the two speedometers (analogue and digital) on the three tasks of the experiment.

For reading the speed value (task 1), clear advantages were found for the digital speedometer. The reported cognitive effort was lower with the digital than with the analogue speedometer (13.5 against 34.4; $Z=3.574$, $p<0.001$). The visual distraction (Fig. 2) was also lower with the digital speedometer (total glance time away from road of 392ms against 1020ms with the analogue speedometer; *p*<.001), and the task completion times followed the same pattern (920ms against 1494ms, *p*<.001). The accuracy for the analogue speedometer was quite good (average error less than 1 km/h), but no errors were made with the digital speedometer (*p*<.001).

To tell if the speed value is under or over 50km/h (task 2), the digital speedometer was also better. Total glance duration on the speedometer and task completion times were lower with the digital speedometer than with the analogue speedometer (total glance duration: 418ms against 643ms, *p*<.001; task completion times: 1038ms against 1146ms, *p*<.001). No significant difference was found regarding accuracy and cognitive distraction (18.9 for the digital and 22.2 for the analogue, *p*=.334).

On the contrary, to tell if the speed is decreasing or increasing (task 3), the analogue speedometer was more appropriate. Away from road glances were reduced by about 155ms (900ms against 1054ms, *p*<.001), and task completion by about 410ms (1397ms against 1804ms, *p*<.001).

Regarding usability, both speedometers were perceived as usable by drivers and every dimension’s scores were good. Only the propensity to error was perceived differently. Drivers reported that they feel they can make more errors with the analogue speedometer (3.68 against 4.83, *Z*=3.180, *p*<.001). Global preference goes to the digital speedometer: 13 drivers on 18 preferred the digital speedometer. Drivers scored better the digital (8.17) than the analogue speedometer (6.78, *Z*=2.792, *p*<.001).

These results, dependent of the task performed, are completely in line with the previous literature [5–11]. The differences between both speedometers are even more pronounced in this study (e.g. digital speedometer minimizing eyes-off-road time from 628ms against 70ms in the study of Ishii, 1980)[8]. The usability and satisfaction results meet conclusions from studies conducted with car drivers [2]. However, the preference for digital over analogue displays may reflect their familiarity with these displays. Indeed, most of participants report using a digital speedometer in the trucks they use to drive. It is interesting to note that 2 drivers quoted differently the grade and the ranking (i.e. give a better score to digital but rank analogue first). They reported that they find digital more usable but prefer having an analogue speedometer for aesthetic reasons.

Globally, the digital speedometer seems to be a good trade-off on the three tasks. Despite the fact that an analogue speedometer would save 155ms of eye off-road time to judge a speed change, the gains in term of visual distraction for the task 1 and 2 (respectively 628ms and 225ms) are significantly more consistent. For the speed reading task, the gain of almost 700ms represents a distance of 16m at 90km/h with the eyes on road.

6 CONCLUSION

This experiment compared an analogue and a digital speedometer in terms of usability and distraction in simulated truck's driving. The results existing in the literature for cars on mechanical instrument clusters have been replicated and extended to truck drivers on a screen instrument cluster. Future research can build on these results to investigate new speedometer representations that would be more efficient for the three reading types. For example, it would be interesting to evaluate if redundant speedometer (i.e. combination of analogue and digital speedometers) could couple the gains of both types presented isolately.

7 REFERENCES

[1] Victor, T., Bärgman, J., Boda, C.N., Dozza, M., Engström, J., Flannagan, C., Lee, J.D., Markkula, G.: 'Analysis of Naturalistic Driving Study Data: Safer Glances, Driver Inattention, and Crash Risk', Transportation Research Board SHRP 2 Reports, 2015, No. S2-S08A-RW-1

[2] Recarte, M.A., and Nunes, L.: 'Mental load and loss of control over speed in real driving. Towards a theory of attentional speed control', Transportation Research Part F, 2002, 5, pp.111–122

[3] Bedinger, M., Walker, G. H., Piecyk, M., & Greening, P.: '21st century trucking: A trajectory for ergonomics and road freight', Applied Ergonomics, 2015, 53, pp. 343–356

[4] Volvo Trucks: ‘European Accident Research Safety Report 2013’, Volvo Trucks European Accident Research Safety Reports, 2013

[5] Simmonds, G. R. W., Galer, M., and Baines, A.: ’Ergonomics of electronic displays’, SAE Technical Paper, 1981, No. 810826

[6] Haller, R.: ‘Experimental investigation of display reading tasks in vehicles and consequences for instrument panel design’, Vision in Vehicles, 1991, 3, pp. 197–203

[7] Green, P.: ‘Human factors and gauge design: a literature review’, UMTRI Reports, 1988, No. UMTRI-88-37

[8] Ishii, I.: ‘Comparison of visual recognition time of analogue and digital displays in automobiles’, SAE Technical Paper, 1980, No. 800354

[9] Castro, C., and Horberry, T.: ‘The effects of different display types with respect to reading numerial information and detecting speed change’, International Conference on Traffic and Transport Psychology-ICTTP, Berne, Switzerland, September 2000

[10] Walter, W.: ‘Ergonomic information evaluation of analogue and digital coding of instruments in vehicles’, Vision in Vehicles, 1991, 3, pp. 205-211

[11] Kiefer, R. J., and Angell, L. S.: ‘A comparison of the effects of an analog versus digital speedometer on driver performance in a task environment similar to driving’, Vision in Vehicles, 1993, 4, pp. 283–290

[12] Zijlstra, F.R.H., and Van Doorn, L.: ‘The Construction of a Scale to Measure Perceived Effort’, Delft University of Technology Reports, 1985

[13] Nielsen, J.: ‘Usability engineering’ (Elsevier Science Publishers, 1994)

Paper III

Digital, analogue, or redundant speedometers for truck driving: Impact on visual distraction, efficiency and usability

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Digital, analogue, or redundant speedometers for truck driving: Impact on visual distraction, efficiency and usability

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A B S T R A C T

Existing literature does not draw conclusions as to which speedometer type is better for truck driving. A digital speedometer would be more beneficial when obtaining absolute and relative readings, while an analogue speedometer would be more efficient and less distracting when detecting dynamic speed changes. Redundant speedometers, which simultaneously present digital and analogue speedometers, appear increasingly in vehicles, but no information is available on their ergonomic qualities. This study compared three speedometers: digital speedometers, analogue speedometers, and redundant speedometers. This study compared the efficiency, usability and visual distraction measures for all three types of speedometers in a simulated truck driving setting. The task-dependant results were confirmed for the digital and analogue speedometer. The redundant speedometer combined the benefits of each type presented separately, which highlights interesting theoretical and applied implications.

1. Introduction

Speed is an essential piece of information that is necessary in order to driver in a proper manner. In addition to visual, auditory and vestibular cues, the speedometer on the dashboard provides an accurate speed reading for the driver, and provides assistance to the driver, so that the driver may properly assess the rate of speed by which they are travelling (Navarro et al., 2011). The design of the speedometer in trucks is critical for road safety, and is especially important for minimizing the need to glance to the side of the road. A misjudgement in the rate of speed is the second most common contributing factor to accidents where the truck driver was the cause (Volvo Trucks European Accident Research Safety Report, 2013). Speeding can lead to a rollover in a bend (particularly for concrete mixer trucks), jack-knifing when braking, or swinging out of control on slippery roadways (Volvo Trucks European Accident Research Safety Report, 2013). In the trucking industry, speedometers are mainly analogue. These speedometers consist of a moving indicator that slides along a scale. However, with the arrival of screen instrument clusters, the speedometer design is no longer constrained by technical reasons. Moreover, with the expansion of speed regulation systems, an increasing number of speed-related information appears on dashboards. This includes items such as adaptive speed limiters and cruise control systems, where the target speed is chosen by the driver. Truck designers are now facing new challenges, and require knowledge on the best way to present vehicle speed, in order to ensure fast, accurate and safe use of the truck.

In the human factors literature, studies focused mainly on two major speedometer types: analogue and digital speedometers. The efficiency of both speedometer types seems to be dependent on which task is performed. In an on-road study, Ishii (1980) reported

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that when drivers look at the digital speedometer, drivers look at it for less time than they look at an analogue speedometer, when engaging in normal driving conditions. More specifically, the amount of time that drivers using a digital speedometer spent looked at the speedometer was on average 70ms shorter than when a driver looked at an analogue speedometer. Simmonds et al. (1981) conducted three studies with a total of 400 drivers, which studies compare different speedometer displays, including digital and analogue speedometers. Results showed that the digital speedometer was more accurate than the analogue speedometer when reporting the actual rate of speed. However, when the speed value was compared to a limit, the accuracy was good for both types of speedometers. For both tasks, the digital speedometer reduced response times, increased usability, and was preferred by drivers. In addition, the number of subjective distractions were more balanced, depending on the driving environment. More specifically, the digital speedometer ranked as being less distracting in the on-road study, when compared to the simulator study. Likewise, Haller (1991) reported that a digital speedometer would be quicker to report a value that an analogue speedometer. Based on a complete review, Green (1988) argued that digital speedometers would be read more rapidly and accurately than analogue speedometers, and recommended that this type of speedometer be used by interface designers.

In contrast, in an on-road study, Walter (1991) reported that drivers using an analogue speedometer made more brake adjustments, and glances less at the speedometer than when using a digital speedometer. They added that even if the duration per glance was longer for the analogue speedometer, the duration of time spent with each driver's eyes off the road was shorter with the analogue speedometer than it was with the digital speedometer. The difference was noted as being on average, a difference of 1.5 s. Drivers also reported less stress and more control with the analogue speedometer (Walter, 1991). Similarly, Kiefer and Angell (1993) outlined a clear advantage for the analogue speedometer, when compared to the digital one. The analogue speedometer was found to be more effective for speed maintenance tasks, and it minimised visual distraction. This was the case even through there were a higher number of glances, as each glance was for a shorter duration. Finally, a more recent article presented three experiments that compared an analogue speedometer and a digital speedometer. Castro and Horberry (2004) reported that the digital display resulted in a slightly reduced response time when compared to the analogue speedometer. This occurred when it was being determined if the speed was over or under a limit, but this effect was reversed when the task was to detect changes in speed. With regard to subjective measures, Olaverri-Monreal et al. (2013) asked participants to prioritise different driving information for in-vehicle car displays. Both analogue and digital speedometers were listed as a first priority, but the analogue type was preferred by 71% of the participants.

The digital speedometer would be more appropriate when obtaining an absolute reading of the speed value (Green, 1988; Haller, 1991; Ishii, 1980; Simmonds et al., 1981) and a relative reading, such as comparing it to a target speed (Castro and Horberry, 2004; Simmonds et al., 1981). However, reading a dynamic speed change would be more efficient and less distracting with an analogue speedometer than it could be with a digital speedometer (Castro and Horberry, 2004; Kiefer and Angell, 1993; Walter, 1991).

Another speedometer type that is appearing in new vehicles has, to the best of our knowledge, never been investigated in the literature discussing human factors. Redundant speedometers, which combine an analogue speedometer and a digital speedometer in the same instrument cluster, raise questions about whether the combined system can be processed efficiently. In fact, the same information is presented concurrently in two different forms. Even if cross-modal redundancy is mainly reported as being beneficial and a facilitator (e.g. Liu, 2001; Wickens and Hollands, 2000), under these circumstances, the same information is displayed two times in a single modality. As a result of the cognitive load theory, researchers in instructional design (Sweller et al., 1998), argued that the same repeated information would degrade an individual's ability to process and comprehend, due to an increase in the external cognitive load. This principle, called redundancy effect, assumes that the different cues that are used simultaneously within the same modality would interfere with each other (Kalyuga et al., 2003; Wickens, 2002). Nonetheless, other researchers reported that a combination of text and symbols produced a better performance, than each one did when presented alone (Coury and Pietras, 1989; Baber and Wankling, 1992). Therefore, it is interesting to investigate if the redundant presentation of both speedometer types could either facilitate the completion of the task, such as drivers selecting the relevant information for a task, or produce an interference effect, where redundancy would degrade the ability to process information.

Most studies involving car drivers were conducted more than 20 years ago. Social changes (i.e. different relation to speed due to the strengthening of the regulation and road controls), technology changes (i.e. the expansion of digital types in the everyday life), and changes in term of context of use (e.g. accuracy needed to choose a cruise control target speed) could impact drivers' interaction with the speedometer. When compared to car drivers, truck drivers' eye distance to the instrument cluster is doubled to approximately 60 cm, and the angle is increased. Researches showed that the difference of display positions between cars and trucks can influence a driver's glance behaviour (Larsson et al., 2017). Moreover, truck drivers spend most of their time on the road in a professional context. This can include up to 56 h in any given work week (Bedinger et al., 2015). In addition, the difference in vehicle speed variation, due to vehicle weight, could impact their speed management and control mechanisms. Most of these assessments were conducted using analogue hardware, and it is essential to see if the benefits and tasks' specificities are preserved for screen instrument clusters. Moreover, studies were conducted based on basic tasks, such as reading the speed, comparing the speed to a target, or detecting a speed change. More complex use cases are missing in the literature, and may have different effect on drivers' behaviours and attitudes toward each speedometer type. For example, when displaying a road's speed limit on a traffic sign, the analogue scale might be processed more rapidly than when it is presented next to a digital display, which is benefiting from a spatial cue. In the Rasmussen's skill-rules-knowledge model (1983), performance levels are based on different levels of information perception: signals, signs, and symbols. This difference in perception of information is due to context. More specifically, it is based on what information the user will use to achieve a given task. A digital speedometer would be processed at a sign perception level. Indeed, all tasks rely on rules, such as reading the value and comparing it to a value in memory, in order to determine if you are exceeding the speed limit. An analogue speedometer would be processed as a sign to report a speed value or compare it to a target speed. However, the ability to detect a speed change would benefit from signals that are provided by the continuous sensory-motor aspect associated with the movement of the pointer. The completion of this task would then rely on a skill-based behavioural level. Tasks using these different levels are required, in order to consider all processing aspects associated with each speedometer type.

This study compared three speedometers (digital, analogue and redundant) on efficiency, usability and visual distraction measures for truck driving. Speedometers were presented on a screen instrument cluster and assessed on contemporary use cases, such as comparing the truck's speed against the road's speed limit sign. The first objective was to update the existing literature on digital and analogue speedometers that have screen dashboard uses, and to examine the validity of the findings for truck drivers. The second objective was to evaluate the distraction, efficiency, and usability of a redundant speedometer, as opposed to the more traditional digital and analogue speedometers. Finally, the third objective was to assess and compare the three speedometer types while using speed management systems, such as cruise control, adaptive speed limiters, and the displaying of the road's speed limit.

2. Material and methods

2.1. Participants

A group of 18 trucks drivers took part in the experiment. All of the truck drivers were men, with a mean age of 42 ($SD = 5.5$). All participants held valid truck driving licences, with an average holding period of 16 years ($SD = 8.8$). Most participants drove a truck several times a month (78%). All reported normal or corrected-to-normal vision and hearing. When driving a car, 67% of the participants used an analogue speedometer, 28% a digital speedometer, and 5% used a redundant speedometer. When driving a truck, 78% of the participants used a digital speedometer, and 22% used either an analogue or a digital speedometer, depending on which truck the participant was driving. None of the participants regularly drove a truck with a redundant speedometer. Written informed consent was obtained from each participant.

2.2. Equipment

A fixed-base medium-fidelity driving simulator was used. The simulator was composed of a truck seat, two-thirds of a real dashboard, and a 65 inch plasma screen that used Oktal SCANeR™ for traffic scenario display and truck modelling. Original accelerator pedal, brake pedal and a steering wheel from a Renault Trucks T were used. A highway environment was used, complete with simulated random traffic around the vehicle. A 15.4 inch screen was located in place of the instrument cluster behind the steering wheel, in order to display stimuli. The height of the screen was 332 mm, the width of the screen was 207 mm, and the resolution was 1280 × 800. A binocular head-mounted eye tracker was used to capture eye gaze (Tobii Glasses 2; scene camera resolution: 1920 × 1080; eye camera tracking frequency: 50 Hz). Gaze raw data were filtered using the Tobii I-VT fixation filter configured so that short fixations were not discarded (Olsen, 2012).

2.3. Material

2.3.1. Speedometers

The digital speedometer was a two digit display (font: Myriad Pro; height: 18 mm; Figs. 1-a). The km/h unit was displayed in lower case next to the digits (font: Myriad Pro; height: 5 mm). The refresh rate of the digits was 1.25 Hz (refresh rate of the screen: 60 Hz). The analogue speedometer was composed of a semi-circular fixed scale (width: 100 mm, height: 50 mm) graduated inside (length: 3 mm) and marked outside all 10 km/h from 0 and 120 km/h (font: Myriad Pro; height: 5 mm; Fig. 1-b). The moving pointer was a non-complete needle pointing the scale (10 mm long, attached to the scale). The km/h unit was displayed in small print at the beginning of the scale (font Myriad Pro; height: 3 mm). For the redundant speedometer, the digital speedometer was presented at the centre of the analogue speedometer (Fig. 1-c). All speedometers were presented centred in upper half of the screen. Decision on the graphic characteristics of the three speedometers have been taken considering existing fully reconfigurable clusters in cars (e.g. the needle is often cut off to display something inside), and the existing human factors knowledge (e.g. scale should be numbered in increments of 10; Green, 1988).

2.3.2. Tasks performed

The participants were required to perform a primary driving task which was to follow a red car on a highway. Moreover, each speedometer was tested using three different reading types: an absolute reading, a relative reading, and a dynamic reading. Three tasks, without additional speed information (i.e. pure driving) were proposed:

- Task1 (absolute reading): ‘read the speed value’ (answer: number)
- Task2 (relative reading): ‘determine if the speed is under or over 50 km/h’ (answer: plus or minus)
- Task3 (dynamic reading): ‘determine if the speed is increasing or decreasing’ (answer: increase or decrease)

Moreover, three tasks implying additional speed information (i.e. driving with speed regulation systems) were proposed (Figs. 1–2):

- Task4 (absolute reading): ‘read the speed value’ (answer: number)
- Task5 (relative reading): ‘determine if the speed is under or over the road speed limit (displayed on the speedometer)’ (answer: plus or minus)
- Task6 (dynamic reading): ‘determine the moment when the speed reach the cruise control target speed (as in a situation of pressing the ‘resume’ button of the cruise control)’ (answer: top)

The instrument cluster remained black while driving. Drivers could maintain vehicle speed by adjusting the distance from the red car. The speedometer was displayed only during tasks and only from the start of the task until the driver provided an answer. Thus, it avoided having the driver look at the speedometer before the task. Moreover, the speed value displayed during each event was not related to the vehicle's current speed. By proceeding in this manner, reading times were entirely based on the type of display and the speed values that were being displayed could be controlled.

For the task 1, 4 stimuli were proposed (2 randomly chosen between 31 and 44 km/h and 2 between 51 and 64 km/h). For the task 2, 8 stimuli were proposed (4 randomly chosen between 41 and 48 km/h and 4 between 52 and 59 km/h). For the task 3, 8 stimuli were proposed (2 decelerations and 2 accelerations with an initial speed randomly chosen between 36 and 41 km/h, and 2 decelerations and 2 accelerations with an initial speed randomly chosen between 56 and 61 km/h). For the task 4, 4 stimuli were proposed (2 randomly chosen between 31 and 44 km/h and 2 between 51 and 64 km/h). Additional information displayed was the road speed limit sign and the speed limiter target speed. For the task 5, 8 stimuli were proposed (2 randomly chosen between 41 and 48 km/h and 2 chosen between 52 and 59 km/h with the road speed limit at 50 km/h, and 2 randomly chosen between 61 and 68 km/h and 2 chosen between 72 and 79 km/h with the road speed limit at 70 km/h). Additional information displayed was the road speed limit sign. For the task 6, 4 stimuli were proposed (1 slow acceleration – $0.21 m/s^2$ – and 1 fast acceleration – $1.26 m/s^2$ – with an initial speed randomly chosen between 38 and 42 km/h and a cruise control target at 52 km/h, and 1 slow acceleration – $0.21 m/s^2$ – and 1 fast acceleration – $1.26 m/s^2$ – with an initial

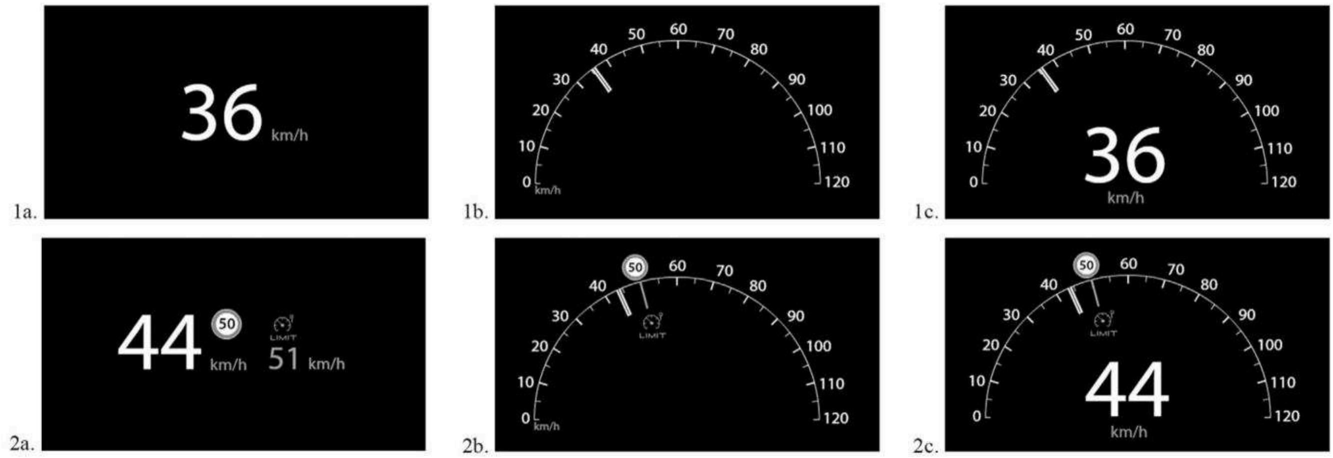

Fig. 1. a. Digital speedometer. b. Analogue speedometer. c. Redundant speedometer; (1) Representation of the speedometers for the tasks 1, 2, and 3. (2) Representation of the speedometers with additional speed information (example for the task 4).

Fig. 2. Experimental setup.

speed randomly chosen between 58 and 62 km/h and a cruise control target at 72 km/h).

2.4. Procedure

Before the experimental phase, participants were informed of the details of the study, and each participant completed a consent form. After these steps were completed, the eye tracking device was positioned and calibrated. The participants were given a 10 min training, in order to familiarise each participant with all of the speedometers and each of tasks. For each test drive, participants were required to follow a red car on a highway. The question drivers had to answer was stated by the experimenter before departure. During most of the experiment, the information cluster remained black. Every 6–8s (randomly) a sound announced that the speedometer was about to be displayed (Fig. 2). Thereafter, the driver could then give his answer aloud, which would result in a removal of the display. The experiment was composed of three test drives, each of which corresponded to the three speedometer types. The three test drives each containing the six tasks. A usability questionnaire was proposed after each test drive (cf. data acquisition and analysis section). At the end of the experiment, participants were asked to report their preferences, by providing a list that ordered their preferences, and by assigning grades to each preference.

Each participant was tested individually, and each participant experienced all conditions. The order in which the experimental condition were presented was counterbalanced by following Latin squares, crossing the speedometer types, the task group (i.e. simple driving or driving with additional information), and the tasks. The presentation of the stimuli was randomly arranged for each session. The total test duration was approximately one hour.

2.5. Data acquisition and analysis

Visual distraction was analysed by calculating the mean number of glances away from the road and the mean total off-road glance duration. The glance times were computed from the time the stimulus was displayed until the time the driver started to give their answer. The efficiency was assessed through task completion times, measured as the time in milliseconds between the display of the stimulus and the answer of the participant. In addition, the efficiency was assessed using accuracy scores, measured as the absolute distance between the driver's answer and the real value displayed). Perceived usability was examined through a questionnaire composed of five 5 points Likert scales, each of which corresponded to the five constructs of usability, as defined by Nielsen (1994). The five constructs are learnability, efficiency, memorability, errors, and satisfaction. The goal of this questionnaire created for the study, was to offer a consistent subjective measure which could be compared to each of the three speedometers for each construct. In addition, the goal was to have it easy to follow and easy to respond to. Each item consisted of an affirmation based on the construct definition, and was associated with a Likert scale from 1 meaning: 'totally disagree', to 5, which meant: 'totally agree' (Appendix 1). Finally, driver satisfaction was measured at the end of the experiment. The order of preference (from 1 to 3) was collected orally. One represented the most satisfying speedometer, and three represented the least satisfying speedometer. The satisfaction score was collected for each speedometer using an 11 point Likert scale. In this scale, zero meant 'not satisfying at all', and ten meant 'very satisfying').

To compare the means of the three matched groups that corresponded to the three speedometer types, one-way repeated ANOVA measures were performed for each task, and were based on total glance duration and task completion times (within-subject factor manipulated: speedometer with three modalities: digital, analogue and redundant). To compare the three speedometers on the paired tasks (i.e. same question with and without additional speed information), 3 × 2 repeated measures ANOVA were performed on the glance and task completion times. The within-subject factors manipulated were: speedometers (digital, analogue, redundant) and tasks (absolute/relative reading without additional information: Task 1/Task 2, absolute/relative reading with additional information: Task 4/Task 5). The tasks 3 and 6 were not considered as paired tasks because the questions asked were different. Values apart from the mean value minus or plus two standard deviations were discarded from the data analysis (less than 5% of the data). Tukey HSD post-hoc tests were leaded to determine significant differences of means between groups of the ANOVA. Non-parametric Wilcoxon tests for paired samples and Friedman tests were performed for the number of glances, accuracy scores, usability questionnaire and satisfaction measures. For the usability questionnaire, single item scores were computed to measure each of the five constructs.

3. Results

3.1. Visual distraction

For the **task 1**, the main effect of speedometer type was significant ($F(2,34) = 102.21$, $p < 0.001$, $\eta_p^2 = 0.84$) indicating a higher total glance duration (Fig. 3) with the analogue speedometer (1071ms) than with the digital (368ms; $p < 0.001$) and the redundant speedometer (462ms; $p < 0.001$). The same results were found for the **task 4**, with a significant effect of speedometer ($F(2,34) = 140.92$, $p < 0.001$, $\eta_p^2 = 0.89$) showing a higher total glance duration with the analogue speedometer (1300ms) than with the digital (456ms; $p < 0.001$) and the redundant speedometer (522ms; $p < 0.001$). The 3 × 2 repeated-measures ANOVA revealed significant main effects of the speedometer ($F(2,34) = 181.73$, $p < 0.001$, $\eta_p^2 = 0.91$), of the tasks ($F(1,17) = 16.69$, $p < 0.001$, $\eta_p^2 = 0.50$), and the two-way interaction ($F(2,34) = 4.05$, $p = 0.027$, $\eta_p^2 = 0.19$). Post-hoc tests showed that, with the analogue speedometer, the total glance duration was significantly lower for task 1 than for task 4 (respectively 1071ms and 1300ms; $p < 0.01$).

For the **task 2**, the one-way repeated measures ANOVA showed a significant effect of the speedometer ($F(2,34) = 63.69$, $p < 0.001$, $\eta_p^2 = 0.79$) highlighting that the analogue speedometer (686ms) implied higher total glance duration than the digital (326ms; $p < 0.01$) and the redundant speedometer (457ms; $p < 0.01$). Similarly, the redundant speedometer implied longer glance duration than the digital speedometer ($p < 0.01$). These results were not found for the **task 5**, for which no significant differences were found between the speedometers regarding the total glance duration (742ms for the digital, 722ms for the analogue, and 779ms for the redundant; $F(2,34) = 0.84$, $p = 0.439$). The 3 × 2 repeated-measures ANOVA revealed significant main effects of the speedometer ($F(2,34) = 20.28$, $p < 0.001$, $\eta_p^2 = 0.54$), of the tasks ($F(1,17) = 56.04$, $p < 0.001$, $\eta_p^2 = 0.77$), and the two-way interaction ($F(2,34) = 24.57$, $p < 0.001$, $\eta_p^2 = 0.59$). Post-hoc tests showed that the total glance duration was significantly higher for the task 5 than for the task 2 for with the digital speedometer (Task 2: 326ms, Task 5: 742ms; $p < 0.001$) and with the redundant speedometer (Task 2: 457ms, Task 5: 779ms; $p < 0.001$).

For the **task 3**, the effect of speedometer was significant ($F(2,34) = 36.67$, $p < 0.001$, $\eta_p^2 = 0.68$). The total glance duration away from the road was higher with the digital speedometer (877ms) than with the analogue (563ms; $p < 0.001$) and the redundant speedometer (633ms; $p < 0.001$).

For the **task 6**, no significant difference of total glance duration was found between the three speedometers (4604ms for the digital, 4320ms for the analogue, and 4213ms for the redundant; $F(2,34) = 1.45$, $p = 0.249$). However, the digital speedometer implied significantly higher number of glances than the analogue speedometer (respectively 5.04 and 4.26 glances; $Z = 3.419$, $p < 0.001$, $r = 0.57$; Fig. 4) and the redundant speedometer (4.21 glances; $Z = 3.067$, $p = 0.002$, $r = 0.51$).

3.2. Efficiency

Objectives measures of efficiency were collected: task completion times (Fig. 5) and accuracy (i.e. absolute distance between the driver's answer and the value displayed; Fig. 6). For the **task 1**, the main effect of speedometer was significant ($F(2,34) = 177.85$, $p < 0.001$, $\eta_p^2 = 0.91$) indicating longer completion times with the analogue speedometer (1442ms) than with the digital (795ms; $p < 0.001$) and the redundant speedometer (831ms; $p < 0.001$). The same results were found for the **task 4**: significant effect of speedometer ($F(2,34) = 151.33$, $p < 0.001$, $\eta_p^2 = 0.90$) showing a higher task completion time with the analogue speedometer (1703ms) than with the digital (874ms; $p < 0.001$) and the redundant speedometer (879ms; $p < 0.001$). The 3 × 2 repeated-measures ANOVA comparing the three speedometers on the task 1 and 4 revealed significant main effects of the speedometer ($F(2,34) = 208.04$, $p < 0.001$, $\eta_p^2 = 0.92$), the tasks ($F(1,17) = 40.75$, $p < 0.001$, $\eta_p^2 = 0.71$), and the two-way interaction ($F(2,34) = 12.01$, $p < 0.001$, $\eta_p^2 = 0.41$). Tukey HSD post-hoc test showed that the task completion times were statistically significantly lower for task 1 than for task 4 with the analogue speedometer (respectively 1442ms and 1703ms; $p < 0.01$). Accuracy for the tasks 1 and 4 was significantly better for the digital (Task 1: mean distance 0, $Z = 2.67$, $p = 0.008$, $r = 0.44$; Task 4: mean distance 0, $Z = 3.06$, $p = 0.002$, $r = 0.51$) and for the redundant speedometer (Task 1: mean distance 0, $Z = 2.67$, $p = 0.008$, $r = 0.44$; Task 4: mean distance 0, $Z = 3.06$, $p = 0.002$, $r = 0.51$) than for the analogue speedometer (Task 1: mean distance 0.26; Task 4: mean distance 0.51).

For the **task 2**, the one-way repeated measures ANOVA showed a significant effect of the speedometer ($F(2,34) = 50.72$, $p < 0.001$, $\eta_p^2 = 0.75$) showing that the analogue speedometer (1092ms) implied longer task completion times than the digital (827ms; $p < 0.01$) and the redundant speedometer (921ms; $p < 0.01$). These results were not found for the **task 5**, for which no significant different was found for pairwise comparisons of speedometers (1177ms for the digital, 1100ms for the analogue, and 1189ms for

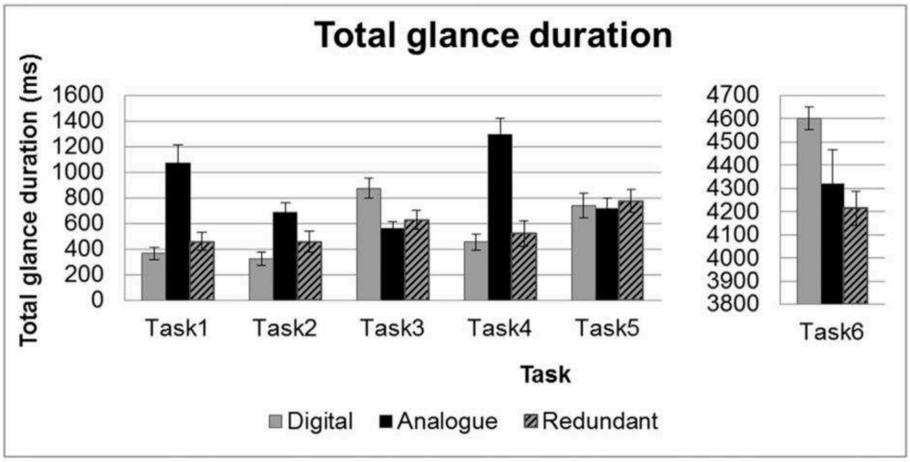

Fig. 3. Total off-road glance duration in milliseconds (with standard deviation) for the three speedometers on the six tasks.

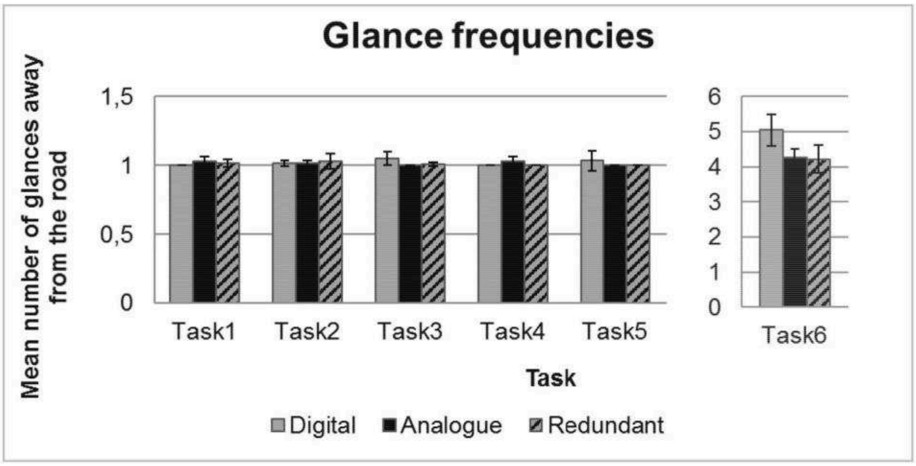

Fig. 4. Mean number of glances away from the road (with standard deviation) for the three speedometers on the six tasks.

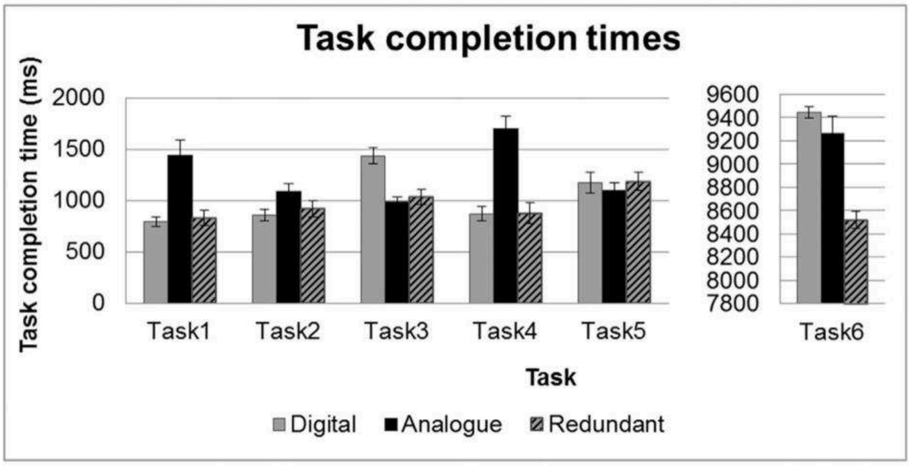

Fig. 5. Task completion times in milliseconds (with standard deviation) for the three speedometers on the six tasks.

the redundant). The 3 × 2 repeated-measures ANOVA revealed significant main effects of the speedometer ($F(2,34) = 18.57$, $p < 0.001$, $\eta_p^2 = 0.23$), the tasks ($F(1,17) = 33.29$, $p < 0.001$, $\eta_p^2 = 0.72$), and the two-way interaction ($F(2,34) = 35.90$, $p < 0.001$, $\eta_p^2 = 0.67$). Tukey HSD post-hoc test showed that task completion times were significantly longer for the task 5 than for the task 2 for with the digital speedometer (Task 2: 827ms, Task 5: 1177ms; $p < 0.001$) and with the redundant speedometer (Task 2: 921ms, Task 5: 1189ms;

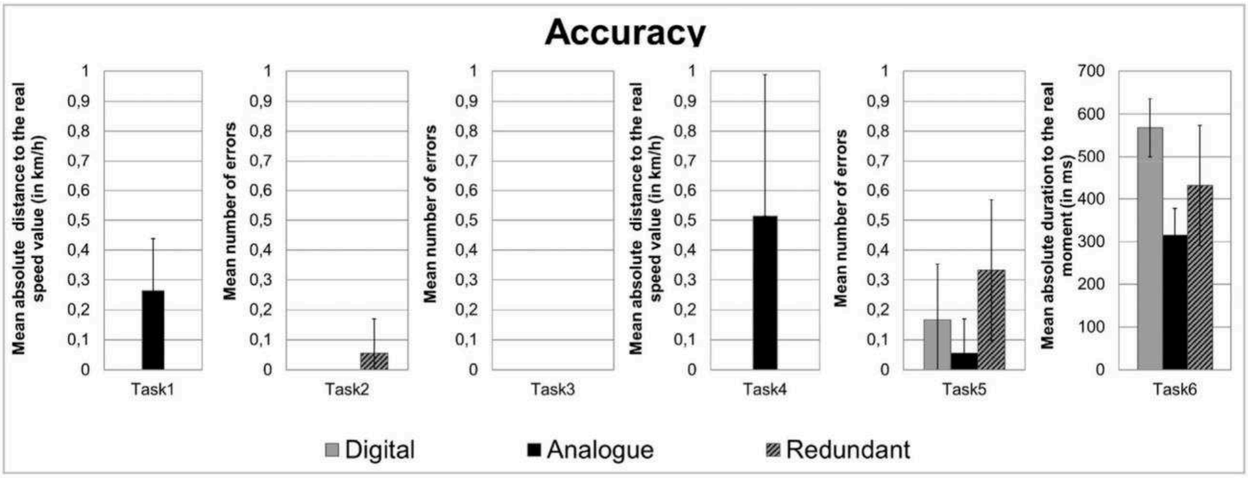

Fig. 6. Accuracy scores (with standard deviation) for the three speedometers on the six tasks. Task 1 and 4: mean absolute distance between drivers' answer and the real speed value displayed. Task 2, 3 and 5: Mean number of drivers' error. Task 6: mean absolute duration between the driver's answer and the real moment when the speed reaches the cruise control target speed.

$p < 0.001$).

For the **task 3**, the effect of speedometer was significant ($F(2,34) = 117.25$, $p < 0.001$, $\eta^2_p = 0.87$). The task completion times were significantly higher with the digital speedometer (874ms) than with the analogue (989ms; $p < 0.001$) and the redundant speedometer (1034ms; $p < 0.001$).

For the **task 6**, no significant difference of task completion times was found (9446ms for the digital, 2598ms for the analogue, and 2229ms for the redundant; $F(2,34) = 3.07$, $p = 0.059$, $\eta^2_p = 0.15$). Nevertheless, accuracy was significantly better with the analogue speedometer (mean distance: 315ms) than with the digital speedometer (mean distance: 568ms; $Z = 3.64$, $p < 0.001$, $r = 0.61$).

3.3. Usability

Pairwise comparisons were led for each dimension of the questionnaire for the three speedometers using Wilcoxon tests. On four of the five dimensions (Fig. 7), the redundant speedometer was scored significantly better than the analogue speedometer (efficiency: respectively 4.67 and 3.61, $Z = 3.01$, $p = 0.003$, $r = 0.50$; memorability: respectively 4.83 and 4.28, $Z = 2.34$, $p = 0.019$, $r = 0.39$; errors: respectively 4.61 and 3.39, $Z = 2.97$, $p = 0.003$, $r = 0.50$; and satisfaction: respectively 4.44 and 3.56, $Z = 3.18$, $p = 0.001$, $r = 0.53$). Memorability scores were significantly higher for the redundant speedometer than for the digital speedometer (respectively 4.83 and 4.44; $Z = 1.96$, $p = 0.050$, $r = 0.33$). Drivers scored higher the analogue speedometer for the willingness to errors than the digital speedometer (respectively 3.39 and 4.22; $Z = 2.10$, $p = 0.036$, $r = 0.35$). Regarding the order of preference, 13 drivers on 18 ranked the redundant speedometer at the first place (mean rank of preference: 1.39/3), and the other 5 chose the digital speedometer (mean rank of preference: 2.06/3). The analogue speedometer was ranked either at the second or third place (mean rank of preference: 2.56/3). Similarly, the satisfaction scores (between 0 and 10) were significantly better for the redundant speedometer than for the analogue speedometer (respectively 8.17 and 6.06; $Z = 3.35$, $p < 0.001$, $r = 0.56$).

4. Discussion

First, this study aimed at investigating whether the existing results in the literature comparing analogue and digital speedometers were still valid for truck driving. When reading the speed value (task 1), the digital speedometer was found to be more

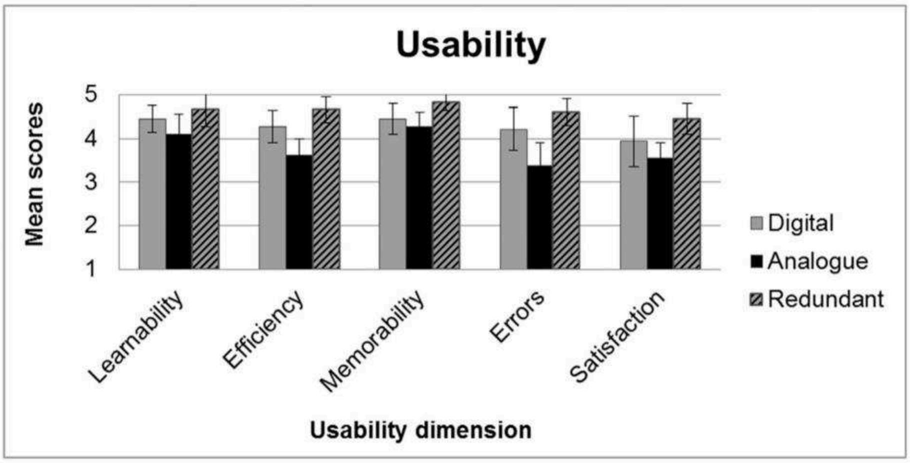

Fig. 7. Mean scores on Likert scales between 1: strongly disagree and 5: strongly agree (with standard deviation) for the three speedometers.

efficient, less visually distracting, and more accurate, when compared to the analogue speedometer. This difference is notable, as the time spent with the eyes off the road was reduced by more than 700ms. The reading was completed about 650ms faster (795ms against 1442ms). Similarly, in the second task, where the participant was asked to tell if the speed value was over or under 50 km/h (task 2), clear advantages were found when using the digital speedometer. More specifically, there was a gain of 360ms of total glance duration on the road, and the task completion time was reduced by 230ms. On the contrary, to tell if the speed is decreasing or increasing (task 3), the analogue speedometer was found to be more appropriate, as there was a gain of 313ms of eyes on the road and the task completion time was 449ms shorter. These results, which are dependent on the task being performed, are completely in line with the previous literature (Ishii, 1980; Simmonds et al., 1981; Haller, 1991; Green, 1988; Castro and Horberry, 2004; Kiefer and Angell, 1993; Walter, 1991). The differences between both speedometers are even more pronounced in this study. More specifically, the digital speedometer minimised the time spent with the eyes-off-road from 703ms in this study, as compared to 70ms in the study conducted by Ishii (1980). The reasons behind this phenomenon were not examined in the literature, but some assumptions were mentioned, in order to explain the advantages of the analogue speedometer when performing a dynamic reading task. An analogue speedometer would provide more speed information in the driver's peripheral vision (Kiefer and Angell, 1993). Thus, the driver would anticipate the pointer position and would get information based on the angle and the movement of the pointer, before having the display in their central vision. Moreover, the analogue speedometer benefits from the dynamic and continuous display of the speed information (Kiefer and Angell, 1993). This continuous information stream allows drivers to know whether the vehicle is accelerating or decelerating without them having to read the exact numerical value. Rather, it provides spatial cues using the dynamic pointer which would help the driver recognise the change in rate and the direction of the change (Castro and Horberry, 2004). However, the digital speedometer is highly dependent of the rate at which it refreshes. Therefore, the information is not continuous and this could impact dynamic reading. These process differences vary depending on the task being performed, and can be related to the skill-rules-knowledge model of Rasmussen (1983). With an analogue speedometer, detecting a dynamic speed change would involve relying on sensory-motor capabilities, which correspond to skill-based performance. Indeed, the analogue speedometer would provide signals that correspond to continuous sensory inputs, which require no reference to any known content associated with the reading task. Rather, with a digital speedometer, the dynamic speed change process would be more complex and would rely on rules. In fact, the driver has to determine if the first speed value is superior or inferior to the second speed value read, in order to conclude if the vehicle is decelerating or accelerating. The use of a procedure known as a rule-based level would match the fact that the task is more expensive with the digital speedometer, than it is with the analogue speedometer. Likewise, to read a speed value with a digital speedometer would be knowledge-based, as would the analogue speedometer. In the usability questionnaire, drivers reported that they could make more errors with the analogue speedometer than they could with the digital speedometer. This result could be due, in major part, to the questions associated with the first task, for which accuracy was better for the digital speedometer. For this task, even if both speedometers were acting like signs, to directly read the value would be less costly than to see the position of the pointer between the graduated level, and then, to interpret the value. To compare the speed value with a target speed, both types of speedometers act like signs, with their readings referring to a rule.

The second objective of this study was to assess the usability, efficiency and visual distraction associated with a redundant speedometer. Results highlighted that the redundant speedometer was effective for the three reading types (i.e. absolute, relative and dynamic). For the task 1 (read the absolute speed value), the redundant speedometer was found to be more efficient, less visually distracting, and more accurate than the analogue speedometer (similar to the digital speedometer performances). The difference between both speedometers resulted in a reduction in the amount of time spent with eyes off of the road by more than 600ms, and would correspond to a driving distance of 15 m with eyes off of the road when travelling at 90 km/h. For the task 2 (tell if the speed value is under or over 50 km/h), the redundant speedometer was also more efficient and less visually distracting than the analogue speedometer. The magnitude of this effect was lower than for the task 1. More specifically, the task was completed about 170ms faster, and the time spend with eyes off of the road decreased by about 230ms. Moreover, the redundant speedometer was more visually distracting than the digital speedometer, with a difference of approximately 131ms. For the task 3 (say if the speed is decreasing or increasing), the redundant speedometer was more efficient and less visually distracting than the digital speedometer (gain about 250ms). Subjectively speaking, the redundant speedometer scored better than the analogue speedometer on four of the usability dimensions. The four usability dimensions are efficiency, memorability, errors, and satisfaction. In addition, the redundant speedometer scored better than the digital speedometer on the memorability dimension. The findings outline the fact that presenting both speedometer types at the same time did not create interference. Furthermore, it performed as well as the best of each individual type for the tasks 1 and 3. For the task 2, the redundant display produced a longer glance duration when compared to the digital speedometer. However, the gap between the redundant speedometer and the digital speedometer was lower (131ms) than the gap between the redundant speedometer and the analogue speedometer (230ms). On average, for the three tasks, the redundant speedometer implied shorter glance duration (1178ms) than both other speedometers (12219ms for the digital; 1444ms for the analogue). Wickens and Gosney (2003) proposed a five-category classification of redundant presentation effects for secondary tasks. This result matches with the 'best of both worlds' pattern, as it describes a redundant display that produced performance equal to or better than the two single conditions. The higher visual clutter does not appear to create a perceived interference, and we can assume that, until an upper limit to the amount of information presented, it would be similar for an entire instrument cluster. In fact, Yoon et al. (2015) showed that the perceived complexity of the speedometer is correlated with the perceived complexity of the whole instrument cluster. Similarly, the repetition of the two speed information system did not created a negative redundancy effect as in instructional design (Kalyuga et al., 2003). The human–machine cooperation model of Navarro (2016) describes the different steps associated to human processing while interaction with a human-machine interface. We can assume that the use of a redundant speedometer would improve perception (attention and perception module in the model), as the total glance duration is reduced. However, it would not impact cognitive processing (situation diagnosis and control module) as no effect was reported on glance frequencies. We can attribute these results to different explanations. First, the fact that task completion times are not prolonged for the redundant speedometer, when compared to the single types presented, indicates that the time spent processing the information did not include additional decision time to choose which type to read. Drivers would automatically select the type that they considered to be better for the task. They would have a metacognitive knowledge of the type chosen for each type of reading, such as looking at the analogue type to detect a dynamic speed change, and looking at the digital type to perform an absolute reading of the speed. Kalyuga et al. (2003) showed that expertise can play a role when processing redundancy. It would be interesting to investigate if this metacognitive knowledge could be linked to truck drivers' expertise, by assessing a redundant speedometer with a novice driver or someone who does not drive at all. Second, Baber and Wankling (1992) argued that the inclusion of redundant information could reduce uncertainty, and therefore reduce decision times. This remaining question could be addressed by evaluating drivers' gaze patterns on the redundant display during the three reading tasks (not performed in this study due to the lack of spatial resolution). Finally, it is important to note that redundancy has a common occurrence in everyday life. Bertelson and De Gelder (2004) stressed that the existence of co-occurring information (whether natural or artificial) create opportunities to improve the performance of perceiving systems.

The third objective of this study was to perform an evaluation on more contemporary uses, such as cruise control, and a display that shows the road's speed limit. This was done in order to complement and update previous results. The absolute reading task include additional speed information (task 4) produced results comparable to the task 1 (the same task without additional information). The analogue speedometer was found to be less efficient, more visually distracting, and less accurate than both other speedometers. The presence of additional information on the speedometer significantly impacted the analogue type, as the time to complete the task was lengthened by 260ms and the time associated with glance duration away from the road was increased by 229ms. For the task 5 (determine if the speed is under or over the road speed limit displayed on the speedometer), no difference was found between the three speedometers. Rather, the advantage associated with the digital speedometer and the redundant speedometers for the same relative reading task without system disappeared (i.e. based on a known target speed). The off-road glance duration and task completion times were increased compared to task 2 (350ms longer for the digital and 268ms for the redundant). For the task 6 (determine the moment when the actual speed reaches the cruise control target speed), the number of glances was higher with the digital speedometer than it was with the analogue and redundant speedometers. Drivers were also more accurate with the analogue speedometer than they were with the digital speedometer. However, the time spent with eyes off of the road and the task completion times were not significantly different between the three speedometers. Therefore, the superiority of the analogue and redundant speedometers for dynamic reading tasks is still present, but the magnitude of the difference has been greatly reduced. These findings show that the gap between the three speedometers is reduced for longer and more complex tasks (task 5 and 6). Moreover, the increase of distraction and task completion times for the digital and redundant speedometers, when comparing the speed to the road speed limit displayed on the dashboard (task 5), is particularly informative for practitioners. In fact, this intelligent driver assistance system generalizes in cars, and further researches should focus on the more efficient way to display the road speed limit, in order to limit the time in which a driver spends with their eyes off of the road. In this study, the same information was presented in two forms over a single-modality, with the modality being vision. Findings showed that the redundant presentation of both speedometer types did facilitate task completion, without degrading the processing of information. However, according to the multiple resource theory (Wickens, 2002), vision resources are limited and can be overloaded. Vision is the sensorial modality that is most used while driving (Sivak, 1996). To solicit another modality could result in the freeing of resources used for the management of visual information related to the primary driving task. For example, it would be interesting to explore a cross-modal redundant speedometer. Other studies have successfully explored the introduction of multimodal interfaces. For example, adding in auditory feedback could improve the amount of visual attention that the driver attributes to the driving scene (to menu navigation for a secondary interface: Tardieu et al., 2015; for an ADAS interface: Houtenbos et al., 2017; for warning interfaces: Biondi et al., 2017) or improve the driver's satisfaction level (Jakus et al., 2015). For our topic, multimodal speedometers have been investigated (Yang and Ferris, 2016) and other designs of visually redundant speedometers were explored, such as speedometers that mix a digital display and ambient colour (Ustwo, 2016). Findings concluded that performances were good for ambient-visual, auditory, and tactile speedometer displays, and that redundancy with an auditory display, such as beat pattern, was beneficial (Yang and Ferris, 2016). Another solution might be to investigate dynamic interfaces, in order to provide additional relevant information (May, 2013; Davidsson and Alm, 2014). This perspective would be particularly suitable for displaying additional speed information, such as displaying the speed limit information only when the speed limit is broken. Indeed, results show that performance was reduced when this information was added. Alternative design solutions for trucks could also be explored in future research.

This study contributes to the current knowledge on this topic, by adding data on redundant speedometers and deepening knowledge on contemporaneous use cases. However, future research should address further issues. First, naturalistic research would be necessary to complement this exploratory study. Even if gaps exist between the three speedometers, which are reduced for more complex tasks using speed regulation systems, this paper presents promising findings in favour of redundant speedometer displays. Kiefer and Angell (1993) reported that an analogue speedometer was more effective for the detection of pedestrians than a digital one. More specifically, on average, 18% of pedestrians were not detected with an analogue speedometer, while an average of 22% of pedestrians were not detected when using digital speedometer. Further research could focus on situational awareness with redundant speedometers, as compared to the traditional speedometer types. Indeed, even if it is essential to prevent overload (i.e. unnecessary high mental workload) while interacting with a speedometer, underload can be detrimental to performance just as it is to mental overload (Young et al., 2015). Besides, the methodological framework of this study lacked ecological validity. More specifically, speedometers were used on a task-based protocol system, and not in natural driving. Indeed, the desire was to isolate performance for each of the three tasks, which would have been mixed during natural driving scenarios. It would be interesting to find similar results for real driving scenarios, when a speedometer always displayed. A naturalistic study would also be beneficial in bringing in objective data, which will assist with the interpretation of these findings. In this study, speedometers were assessed individually on each of the three reading tasks. In a vehicle, the same speedometer is used for the three different reading tasks. As such, it would be necessary to evaluate which proportion of each reading type is used, in order to conclude which is the best speedometer.

5. Conclusions

The design of the speedometer is directly linked to safety considerations. It is essential to provide input to practitioners on the following objectives: quickly providing accurate speed information and minimising time spend with eyes off of the road. With the development of screen instrument clusters and speed regulation systems, the human factors literature presents only limited answers to contemporary concerns. This experiment updated previous literature on analogue and digital speedometers, by confirming task-dependant results for screen instrument clusters. The digital speedometer is more efficient and less visually distracting for absolute and relative reading tasks, whereas the analogue speedometer is more effective for detecting a dynamic speed change. The redundant speedometer has the best performance when compared to the two single types for each of the three reading tasks. Even if gaps between the three speedometers are reduced for more complex tasks using speed regulation systems, this paper presents promising findings in favour of redundant speedometer displays. The findings of this paper meet both theoretical and applied knowledge, have direct design implications for truck dashboards, and contribute to the theoretical work on redundant information processing.

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Appendix 1. Usability questionnaire (adapted from the five usability constructs of Nielsen, 1994)

1. It was easy to use this speedometer for the first time.

Totally disagree						Totally agree
	1	2	3	4	5	

2. This speedometer allowed me to perform the tasks accurately, correctly and quickly.

Totally disagree						Totally agree
	1	2	3	4	5	

3. It would be easy to reuse this speedometer after a period of non-use.

Totally disagree						Totally agree
	1	2	3	4	5	

4. The use of this speedometer can be done without error.

Totally disagree						Totally agree
	1	2	3	4	5	

5. This speedometer is pleasant to use.

Totally disagree						Totally agree
	1	2	3	4	5	

References

Baber, C., Wankling, J., 1992. An experimental comparison of test and symbols for in-car reconfigurable displays. Appl. Ergon. 23 (4), 255–262.
Bedinger, M., Walker, G.H., Piecyk, M., Greening, P., 2015. 21st century trucking: a trajectory for ergonomics and road freight. Appl. Ergon. 53, 343–356.
Bertelson, P., De Gelder, B., 2004. The psychology of multimodal perception. Crossmodal space Crossmodal Atten. 141–177.
Biondi, F., Strayer, D.L., Rossi, R., Gastaldi, M., Mulatti, C., 2017. Advanced driver assistance systems: using multimodal redundant warnings to enhance road safety. Appl. Ergon. 58, 238–244.
Castro, C., Horberry, T., 2004. The effects of different display types with respect to reading numerical information and detecting speed change. Traffic Transp. Psychol. Theory Appl. Proc. ICTTP 2000, 301–315.
Coury, B.G., Pietras, C.M., 1989. Alphanumeric and graphic displays for dynamic process monitoring and control. Ergonomics 32 (11), 1373–1389.
Davidsson, S., Alm, H., 2014. Context adaptable driver information – or, what do whom need and want when? Appl. Ergon. 45 (4), 994–1002.
Green, P., 1988. Human Factors and Gauge Design: a Literature Review (No. UMTRI-88–37). The University of Michigan Transportation Research Institute.
Haller, R., 1991. Experimental investigation of display reading tasks in vehicles and consequences for instrument panel design. Vis. Veh. 3, 197–203.
Houtenbos, M., De Winter, J.C.F., Hale, A.R., Wieringa, P.A., Hagenzieker, M.P., 2017. Concurrent audio-visual feedback for supporting drivers at intersections: a study using two linked driving simulators. Appl. Ergon. 60, 30–42.
Ishii, I., 1980. Comparison of Visual Recognition Time of Analogue and Digital Displays in Automobiles (No. 800354). SAE Technical Paper.
Jakus, G., Dicke, C., Sodnik, J., 2015. A user study of auditory, head-up and multi-modal displays in vehicles. Appl. Ergon. 46, 184–192.
Kalyuga, S., Ayres, P., Chandler, P., Sweller, J., 2003. The expertise reversal effect. Educ. Psychol. 38 (1), 23–31.
Kiefer, R.J., Angell, L.S., 1993. A comparison of the effects of an analog versus digital speedometer on driver performance in a task environment similar to driving. Vis. Veh. 4, 283–290.
Larsson, P., Engström, J., & Wege, C. (2017). Virtual eye height and display height influence visual distraction measures in simulated driving conditions. Submitted to: 5th International Conference on Driver Distraction and Inattention, Paris, France.
Liu, Y.C., 2001. Comparative study of the effects of auditory, visual and multi-modality displays on drivers' performance in advanced traveller information systems. Ergonomics 44 (4), 425–442.
May, A.J., 2013. Using a 'value-added' approach for contextual design of geographic information. Appl. Ergon. 44 (6), 895–908.
Navarro, J., 2016. Human–machine interaction theories and lane departure warnings. Theor. Issues Ergon. Sci. 1–29.
Navarro, J., Mars, F., Young, M.S., 2011. Lateral control assistance in car driving: classification, review and future prospects. Intell. Transp. Syst. IET 5 (3), 207–220.
Nielsen, J., 1994. Usability Engineering. Elsevier Science Publishers, Amsterdam.
Olaverri-Monreal, C., Lehsing, C., Trubswetter, N., Schepp, C.A., Bengler, K., 2013. In-vehicle displays: driving information prioritization and visualization. IEEE Intell. Veh. Symp. 4, 660–665.
Olsen, A., 2012. The Tobii i-vt Fixation Filter. Tobii Technology.
Rasmussen, J., 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. Syst. Man Cybern. IEEE Trans. 3, 257–266.
Simmonds, G.R., Galer, M., Baines, A., 1981. Ergonomics of Electronic Displays (No. 810826). SAE Technical Paper.
Sivak, M., 1996. The information that drivers use: is it indeed 90% visual? Perception 25 (9), 1081–1089.
Sweller, J., Van Merrienboer, J.J., Paas, F.G., 1998. Cognitive architecture and instructional design. Educ. Psychol. Rev. 10 (3), 251–296.
Tardieu, J., Misdariis, N., Langlois, S., Gaillard, P., Lemercier, C., 2015. Sonification of in-vehicle interface reduces gaze movements under dual-task condition. Appl. Ergon. 50, 41–49.
Ustwo, 2016. Are We There yet? Thoughts on in-car HMI. https://usweb-cdn.ustwo.com/ustwo-production/uploads/2016/07/AreWeThereYet_V1.2.pdf (accessed 14.01.2017).
Volvo Trucks, 2013. European Accident Research and Safety Report 2013. http://www.volvotrucks.com/SiteCollectionDocuments/VTC/Corporate/Values/ART%20Report%202013_150dpi.pdf (accessed 14.01.2017).
Walter, W., 1991. Ergonomic information evaluation of analogue and digital coding of instruments in vehicles. Vis. Veh. 3.
Wickens, C.D., 2002. Multiple resources and performance prediction. Theor. Issues

Ergon. Sci. 3 (2), 159–177.
Wickens, C.D., Gosney, J.L., 2003, October. Redundancy, modality, and priority in dual task interference. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 47. SAGE Publications, pp. 1590–1594. No. 13.
Wickens, C.D., Hollands, J.G., 2000. Engineering Psychology and Human Performance, third ed. Prentice Hall, Upper Saddle River, NJ.
Yang, S., Ferris, T.K., 2016, September. Measuring cognitive efficiency of novel speedometer displays. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 60. SAGE Publications, pp. 1941–1945. No. 1.
Yoon, S.H., Lim, J., Ji, Y.G., 2015. Assessment model for perceived visual complexity of automotive instrument cluster. Appl. Ergon. 46, 76–83.
Young, M.S., Brookhuis, K.A., Wickens, C.D., Hancock, P.A., 2015. State of science: mental workload in ergonomics. Ergonomics 58 (1), 1–17.

2.3. Provide human-factors guidelines on gauges design

As for the design of the speedometer, input data was needed by the experts for the definition of the gauges. Indeed, when defining these, the experts take many design decisions (e.g. shape, orientation, type of pointer). It is therefore essential for them to increase the knowledge on the processing of the gauges according to these various parameters so as to ensure a fast and accurate reading of the gauges while driving. This study, presented in Paper IV, was intended to complete human-factors knowledge and serve as input data for the user-centered design.

2.3.1. Objectives

On instrument clusters, and particularly in trucks, there are many gauges requiring a quick and safe reading. This study aimed at increasing knowledge on the best way to design safe and efficient gauges.

2.3.2. Method

Eighteen truck drivers assessed eight gauges with different shapes, orientation, and indicators on three reading tasks (quantitative, qualitative and check reading).

2.3.3. Highlights and application

Results showed that basic changes in gauge design can impact task completion times, eyes off-road duration, and satisfaction. Horizontal gauges and pointer indicators were more efficient and less visually distracting. On the subjective side, circular and horizontal gauges were preferred by drivers. Specific gauge designs implied a gain in visual distraction up to 250ms.

In the following user-centered design concept, experts chose gauges based on these findings. For example, they defined the tachometer as a linear-horizontal-pointer gauge. Indeed, this gauge design was found efficient, safe, and satisfying.

Paper IV

Gauges design on digital instrument cluster: efficiency, distraction, and satisfaction assessment for truck driving

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Gauges design on digital instrument cluster: efficiency, distraction, and satisfaction assessment for truck driving.

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Objective: This study aims at increasing knowledge on the best way to design trucks' gauges on digital instrument clusters.

Background: Trucks are equipped with many gauges that the driver has to monitor while driving. The arrival of digital instrument clusters offers new design possibilities and the human factors literature presents only limited answers on safe and efficient gauge designs.

Methods: Eighteen truck drivers assessed eight gauges with different shapes, orientation and indicators on three reading tasks (quantitative, qualitative and check reading).

Results: Results showed that gauge design impacts task completion times, eyes off-road duration and satisfaction. Horizontal gauges and pointer indicators were more efficient and less visually distracting. On the subjective side, circular and horizontal gauges were preferred by drivers. Specific gauge designs implied a gain in visual distraction up to 250ms.

Conclusion: For the design of gauges on digital instrument cluster, information processing can be facilitated thanks to basic design changes.

Application: This article provides supported and easy to apply requirements to surface vehicles HMI designers.

Keywords: Distraction; HMI design; Interface evaluation; Display design principles; Commercial vehicles dashboards

1. Introduction

Instrument clusters become more and more digital, with information displayed on screens rather than physical dashboards. This technological advance brings many benefits (e.g. flexible and dynamic interfaces), but reading information from a screen could affect human performance. Indeed, studies in instructional design comparing paper and screen reading reported that reading from screens would be slower and less effective for learning and remembering (Dillon, 1992; Mangen, Walgermo & Brønnick, 2013). If this effect is also true for automotive instrument clusters, this impairment could be particularly critical due to the increase in visual distraction while driving. Therefore, the definition of human-machine interfaces (HMI) on digital clusters is a contemporary concern for interface designers to optimize driver-vehicle interaction.

Within dashboards, gauges have always been major components. Oil level gauge was the first instrument installed inside vehicles around 1900 before speedometers (Akamatsu, Green & Bengler, 2013). Nowadays, several gauges are displayed in automotive dashboards to monitor vehicle information, and this is especially true for trucks (Figure 1). Compared to passenger cars, trucks' mechanical configuration and high amount of functions imply an increased number of information to be monitored by the driver (e.g. up to two air pressure circuits, regeneration filters level, fuel additive tank level, etc.). This study focuses on engine gauges excluding the particular case of the speedometer. Indeed, the speedometer context of use is singular, with factors such as temporal pressure, linked with external signals, and connected with speed management systems (François, Crave, Osiurak, Fort & Navarro, 2016). Some truck gauges are monitored at vehicle start (e.g. air pressure gauge), but other gauges can be used while driving at a high speed with traffic around (e.g. fuel gauge). Any improvements in gauge design that could reduce the effort needed to monitor the truck could increase the amount of resources available to perform safely the primary driving task.

In the human factors literature, three types of gauge reading are distinguished: quantitative reading, qualitative reading, and check reading (Endsley, 1988; Sanders and McCormick, 1993).

Figure 1. Example of 2016 truck dashboard (Mack Trucks North America, Series Granite)

'Quantitative reading' is the processing of a precise numeric value (e.g. the engine speed value). 'Qualitative reading' is used to obtain a trend or change in direction (e.g. the quarter of the fuel level). 'Check reading' determines if a value is within a normal range or not (e.g. engine cooling temperature too hot). Today, gauge design is quite inconsistent across trucks manufacturers. Nevertheless, extensive research has been carried out for passenger cars (Green, 1984; Green, 1988; Mayer & Laux, 1992) and aviation (Baker & Grether, 1954; Connell, 1950; Grether, 1949; Grether & Connell, 1948). Three main gauge types were investigated on the different reading tasks: counters or numeric displays, fixed pointer with moving scale, and moving pointer with fixed scale (Baker and Grether, 1954). Counters are reported fast and accurate for quantitative reading, but less suitable for qualitative and check reading (Baker & Grether, 1954; Chapanis, 1960; Green, 1988; Grether, 1949; Sanders & Mc Cormick, 1993). Fixed pointer with moving scale gauges would be globally poor efficient on the three reading tasks compared to other gauge types (Baker & Grether, 1954; Chapanis, 1960; Connell, 1950; Green, 1988; Grether & Connell, 1958). Moving pointer with fixed scale display would be best for qualitative and check reading, and perform well on quantitative reading (Baker & Grether, 1954; Chapanis, 1960; Green, 1984; Green, 1988; Grether, 1949; Grether & Connell, 1958; Sanders & Mc Cormick, 1993). This gauge type is also the main display used in current truck models. Nevertheless, many types of moving pointer with fixed scale exist, with different design attributes such as the marking of the scale, the way of numbering, the shape and orientation of the gauge, or the indicator type. These attributes have been subjects of several experiments and recommendations have been proposed. For instance, color coding would help the understanding and the detection of critical reading (Green, 1984; Mayer & Laux, 1992); numbers for dials can be inside or outside the scale (Kappauf, 1951); scales should be marked in numbers that are even multiples of 10 (Green, 1988); align pointers to the normal value when multiple gauges have to be checked close to each other would reduce reading time and errors (Green, 1988; Warrick & Grether, 1948); etc. Regarding the shape, orientation and indicator, previous research reported that circular gauges might be preferred to linear gauges (Carveth & Adams, 1964; Graham, 1956; Green, 1988; Sleight, 1948), horizontal gauges to vertical gauges (Graham, 1956; Murrell, 1965; Sleight, 1948), and pointers to bargraphs (Mayer & Laux, 1992).

Although literature on gauge design is extensive in related research areas, some knowledge is missing to define truck gauges on digital clusters. Some of the results have been obtained using the tachistoscopic method with controlled exposure time (e.g. 120ms in Sleight, 1948) which would affect results and be too far from what occurs in practice (Grether, 1949). Moreover, there is a lack of a systematic examination of each attribute on each reading type. Indeed, studies often compared few gauge attributes or very different designs on one reading task, which does not allow judging the weight of each attribute and the interaction between them (Sleight, 1948). Some studies analyzed gauge performance with specified nature (e.g. air speed indicator; Grether & Connell, 1948), which make these results less transferable to other natures or new gauges. Considering 'generic' gauges (without nature) would allow attributing results to design changes only, rather on the semantic associated. Finally, it is essential to examine the validity of these findings nowadays (most of them were conducted more than 20 years ago) for trucks drivers on digital clusters. Compared to car drivers, truck drivers' eye distance to the instrument cluster is doubled (about 60cm) and the angle is increased, and truck drivers spend much time on the road in a professional context (up to 56h in any given work week; Bedinger et al., 2015). Their expertise and their particular relation to the vehicle could impact their gauge monitoring process. Most of the assessments were conducted using mechanical or physical supports, and it is essential to investigate if previous findings are confirmed on screen instrument clusters.

Interfaces quality determining in part the driver's ability to perform the primary driving task while monitoring his cluster, it is essential to deliver to practitioners clear and directly applicable design requirements (François, Osiurak, Fort, Crave & Navarro, 2016). This study addressed the following research questions:

- Does gauge design impact efficiency, distraction and satisfaction?
- What attributes really matter in gauge definition?
- Which kinds of gauge displays are best for specific tasks?

Eight gauge designs based on a factorial experimental design with three attributes: shape (circular or linear), orientation (horizontal or vertical), and indicator (pointer or bargraph), were assessed on quantitative, qualitative, and check reading.

2. Material and methods

2.1 *Participants*

Eighteen trucks drivers took part in this experiment (all men, mean age: 43 years, SD: 5.3). All participants held valid truck licenses for 13 years on average (SD: 8.6). Most participants drove a truck several times a month (78%). All reported normal or corrected-to-normal vision and audition. Written informed consent was obtained from each participant.

2.2 *Equipment*

The fixed-base medium-fidelity driving simulator was composed of a truck seat, two thirds of a real dashboard, and a 65 inches plasma screen using Oktal SCANeR^{TM} for traffic scenario and truck model. Throttle pedal, brake pedal, and steering wheel were original parts of a Renault Trucks T. A highway environment was used, with a random traffic around the vehicle. A 15.4 inches screen was located in place of the instrument cluster behind the steering wheel to display stimuli (height: 332mm, width: 207mm, resolution: 1280x800, refresh rate: 60Hz). A binocular head-mounted eye tracker was used to capture the eye gaze (Tobii Glasses 2; scene camera resolution: 1920x1080; eye camera tracking frequency: 50Hz). Gaze raw data were filtered using the Tobii I-VT fixation filter configured so that short fixations were not discarded (Olsen, 2012).

2.3 *Material*

Gauges. Eight gauge representations (Figure 2) were presented centered in upper half of the screen. Gauges were generic (non-associated to a function, e.g. fuel level) for generalizability reasons. They were presented without scale markers and units. Scales were monochromes, divided in 4 parts with internal graduations (block types), with the last half part in red to indicate a warning zone (always at the end of the gauge, such as for a temperature gauge type). A zero marker indicated the reading direction of the gauge. Three gauge attributes were presented and mixed across the eight gauge representations:

- Shape: circular (demi circular gauge; diameter: 40mm) and linear (length: 62.8mm)
- Indicator: pointer (length: 20mm/16mm) and bargraph (white filling of the scale)
- Orientation: horizontal and vertical (90° anti-clockwise rotation)

Tasks performed. The participants were required to perform a primary driving task which was to follow a red car on a highway. Moreover, each gauge was tested on three reading types:

- Task1 (quantitative reading): 'What is the gauge value between 0 and 100?' (answer: a number between 0 and 100)
- Task2 (qualitative reading): 'In which quarter is the gauge value?' (answer: one, two, three or four)
- Task3 (check reading): 'Is the gauge value in the red zone or not?' (answer: yes or no)

For the task 1 and for the task 2, four stimuli were presented for each gauge (1 with the value randomly chosen between 5 and 24; 1 between 25 and 49; 1 between 50 and 74; and 1 between 75 and 95). For the task 3, four stimuli were presented for each gauge (1 with the value randomly chosen between 8 and 47; 1 between 48 and 87; and 2 between 88 and 95).

2.4 *Procedure*

Before the experimental phase, participants were informed of the details of the study and completed a consent form. Afterwards, the eye tracking device was positioned and calibrated. For each test drive, participants were required to follow a red car on a highway. The question drivers had to

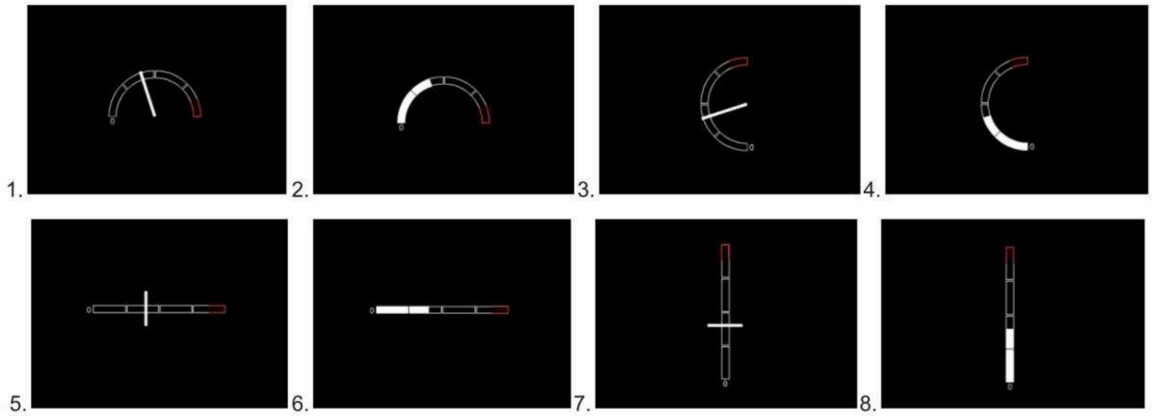

Figure 2. Gauge representations from Gauge 1 to Gauge 8. Gauge attributes are fully mixed: shape (circular from Gauge 1 to Gauge4; linear from Gauge 5 to Gauge 8), indicator (pointer: Gauges with odd numbers; bargraph: Gauges with even numbers); and orientation (horizontal: Gauges 1,2,5 and 6; vertical: Gauges 3,4,7 and 8).

answer was stated by the experimenter before departure. The information cluster remained black most of the time. Every 6 to 8s (randomly) a sound announced that a gauge was about to be displayed. Thus the driver could give his answer aloud (that would remove the display). The experiment was composed of three test drives including all gauge designs (corresponding to the three tasks). At the end of each test drive, participants were asked to report their preferences (order the 8 gauges by preference into three groups for the task performed). Each participant was tested individually and experienced all conditions. The order of the test drives was counterbalanced following Latin squares. Stimuli presentation within each test drive was randomly arranged. The total test duration was approximately 1h.

2.5 Data acquisition and analysis

Efficiency was assessed through task completion times (i.e. time in millisecond between the display of the stimulus and the answer of the participant) and accuracy scores (i.e. task 1: absolute distance between driver's answer and the real value displayed; task 2 and 3: error rate). Visual distraction was analyzed through the total off-road glance duration from stimulus display to the start of driver's aloud answer. Finally, driver satisfaction was scored by the order of preference (from 1 to 8, 1 being the preferred gauge for the task) weighted by the group of ranking (from 1 to 3, the first group being the most liked).

First, analyses were computed on gauge attributes (i.e. shape, indicator, and orientation) for the three tasks (i.e. quantitative, qualitative and check reading) to analyze global differences (regardless of the task). Second, for each task, a three-way repeated measures ANOVA was performed on total glance duration and task completion times (within-subject factors manipulated: shape with two modalities: circular and linear; indicator with two modalities: pointer and bargraph; and orientation with two modalities: horizontal and vertical). Values apart from the mean value plus or minus two standard deviations were discarded from the data analysis (less than 5% of the data). Tukey HSD post-hoc tests were performed to determine significant differences of means between groups of the ANOVA. Gaps of times are presented in milliseconds and in percentages in the discussion (longest duration on the smallest duration). Non-parametric Wilcoxon tests for paired samples and Friedman tests were performed on accuracy and satisfaction scores. A hierarchical cluster analysis was also conducted on satisfaction scores (Ward's method applied to Euclidean distances).

3. Results

3.1 Efficiency

Task completion times (Figure 3) and accuracy scores were collected. Globally (regardless the task performed), the main effect of the task revealed significant (*F*(2,34) = 95.44, *p*<.001), showing that task 1(2058ms) implied longer task completion times that task 2 (1232ms, *p*<.001) and 3 (1128ms, *p*<.001). The effect of orientation was also significant: tasks were performed slower with vertical gauges (1503ms) than with horizontal gauges (1442ms; *F*(1,17) = 12.20, *p*=.003). Similarly, tasks were performed slower with bargraph indicators (1498ms) than with pointers (1447ms; *F*(1,17) = 8.334, *p*=.010). The three-way interaction shape*orientation*indicator was significant (*F*(1,17) = 13.84, *p*=.002) revealing that gauge 5 (1401ms) was significantly more efficient than four other gauges (gauge 4: 1551ms, *p*<.001; gauge 6: 1495ms, *p*=.001; gauge 7: 1512ms, *p*=.003; gauge 8: 1490ms, *p*=.022). On the contrary, Gauge 4 was found less efficient than four other gauges (gauge

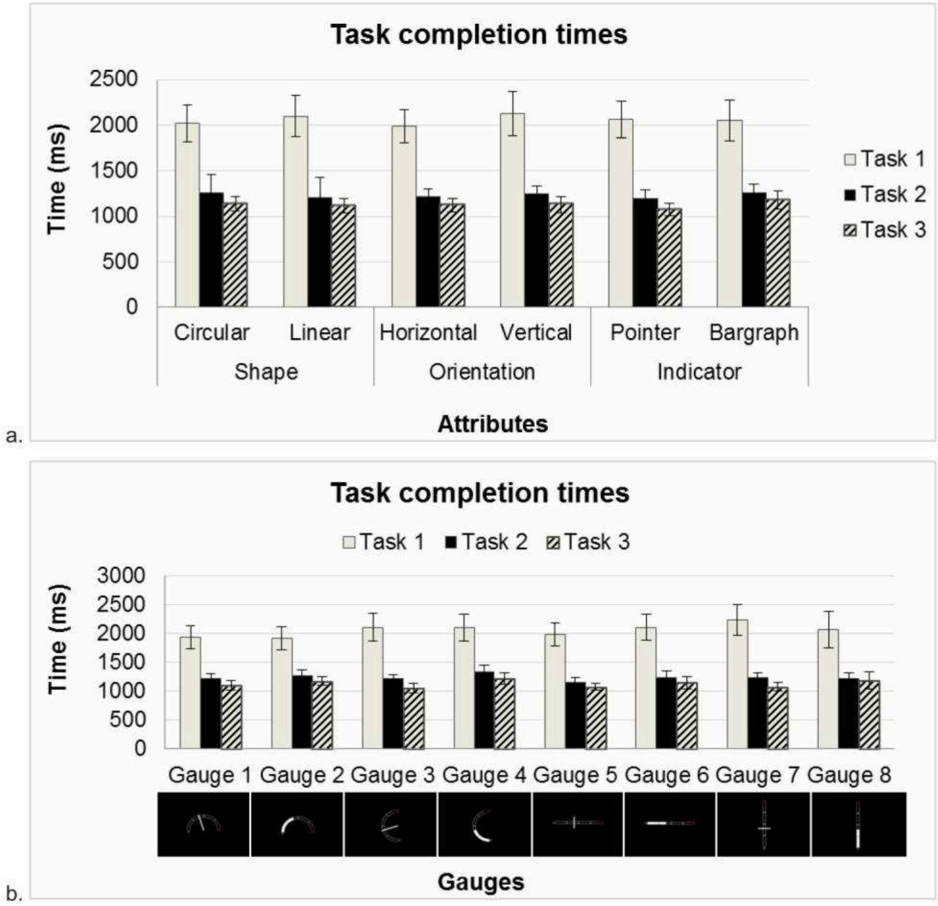

Figure 3. a. Task completion times in milliseconds (± standard deviation) for the three gauge attributes on the three tasks.

b. Task completion times in milliseconds (± standard deviation) for the eight gauges on the three tasks.

1: 1551ms, *p*<.001; gauge 2: 1495ms, *p*=.001; gauge 3: 1512ms, *p*=.003; gauge 5). Gauge 7 was significantly less efficient than gauge 5 and gauge 1 (1418ms, *p*=.014).

For the **task 1**, tasks completion times were lower with horizontal (1987ms) than with vertical gauges (2128ms; *F*(1,17) = 11.45, *p*=.004). The three-way interaction was significant (*F*(1,17) = 7.44, *p*=.014), and Tukey HSD post-hoc test showed that Task 1 was significantly completed faster with Gauge 1 (1940ms, *p*=.001), Gauge 2 (1922ms, *p*<.001) and Gauge 5 (1980ms, *p*=.006) than with Gauge 7 (2232ms). Accuracy was good, and not significantly different between gauge attributes (errors about 2.5% around the real value).

For the **task 2**, tasks completion times were lower with linear (1208ms) than with circular gauges (1255ms; *F*(1,17) = 8.19, *p*=.011). Horizontal gauges (1215ms) were slightly more efficient than vertical gauges (1248ms; *F*(1,17) = 11.62, *p*=.003). Similarly, pointers (1201ms) were slightly more efficient than bargraph indicators (1262ms; *F*(1,17) = 8.39, *p*=.010). Accuracy was good and not significantly different between gauge attributes. The three-way interaction was significant (*F*(1,17) = 5.55, *p*=.031), and Tukey HSD post-hoc test reported that task 2 was completed faster with the Gauge 1 (1214ms, *p*=.045), Gauge 3 (1215ms, *p*=.047) and Gauge 5 (1147ms, *p*<.001) than with Gauge 4 (1327ms). Gauge 5 was more efficient than Gauge 2 (1266ms, *p*=.033) and Gauge 4. The Friedman test reported no significant difference of accuracy between gauges.

For the **task 3**, task was completed faster with pointer gauges (1076ms) than with bargraph gauges (1180ms; *F*(1,17) = 21.13, *p*<.001). Accuracy was good and not significantly different between gauges.

3.2 *Visual distraction*

Visual distraction measures were the total eyes off-road duration (Figure 4). Globally, the main effect of the task revealed significant (*F*(2,34) = 115.12, *p*<.001), showing that task 1(1214ms) implied longer off-road glances than task 2 (673ms, *p*<.001) and task 3 (600ms, *p*<.001). Regardless of the task, vertical gauges (860ms) appeared more visually distracting than horizontal gauges (798ms; *F*(1,17) = 25.46, *p*<.001). Off-road glance durations were also longer with bargraph gauges (863ms) than with pointer indicator gauges

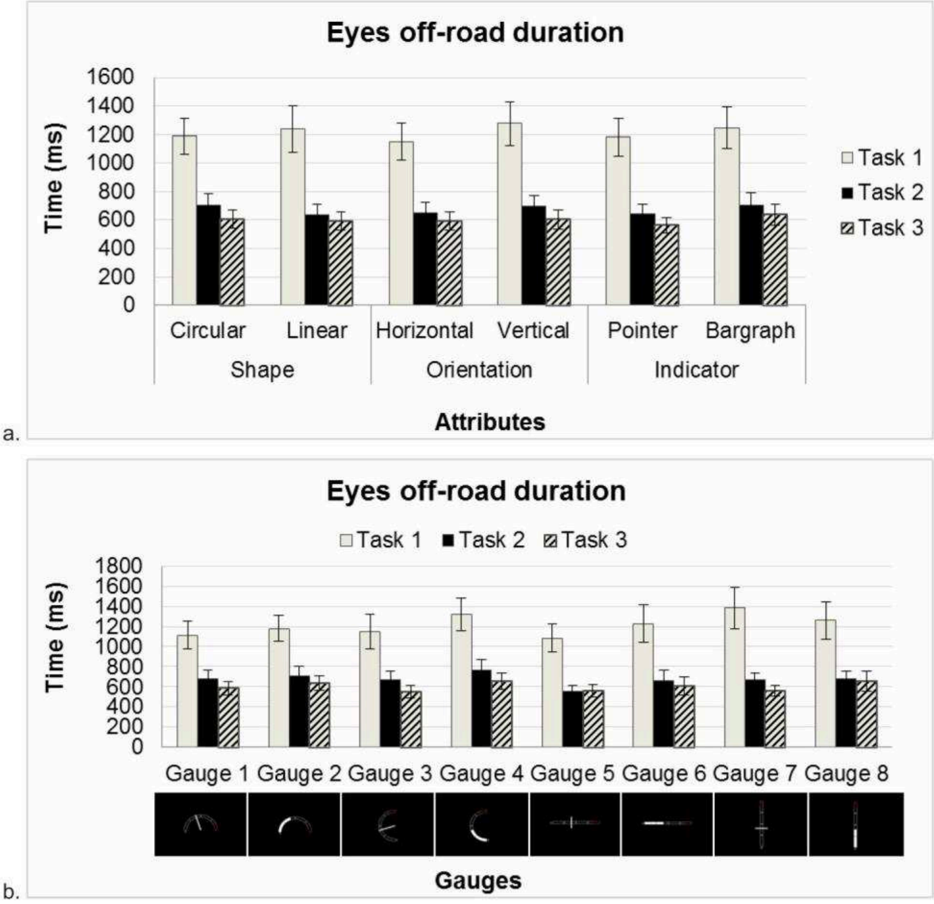

Figure 4. a. Total off-road glance duration in milliseconds (± standard deviation) for the three gauge attributes on the three tasks.

b. Total off-road glance duration in milliseconds (± standard deviation) for the eight gauges on the three tasks.

(795ms; *F*(1,17) = 20.13, *p*<.001). The three-way interaction shape*orientation*indicator was also significant (*F*(1,17) = 9.66, *p*=.006), and post-hoc test reported that Gauge 5 (731ms) was significantly less visually distracting than four other gauges (Gauge 2: 840ms, *p*=.029; Gauge 4: 915ms, *p*<.001; Gauge 7: 870ms, *p*=.004; and Gauge 8: 864ms, *p*=.006). On the contrary, Gauge 4 implied longer off-road glances than four other gauges (Gauge 1: *p*=.010; Gauge 3: *p*=.010; and Gauge 5).

For the **task 1**, the main effect of orientation was significant (*F*(1,17) = 11.71 , *p*=.003) showing that vertical gauges (1277ms) were more visually distracting than horizontal gauges (1151ms). The three-way interaction shape*orientation*indicator was also significant (*F*(1,17) = 6.96, *p*=.017) showing that Gauge 7 (1382ms) was more visually distracting than Gauge 1 (1112ms, *p*= .024) and Gauge 5 (1084ms, *p*= .011).

For the **task 2**, main effects of shape, orientation, and indicator factors reached significance. Circular gauges (706ms) were more visually distracting than linear gauges (640ms; *F*(1,17) = 19.37, *p*<.0001). Vertical gauges (698ms) were more visually distracting than horizontal gauges (648ms; *F*(1,17) = 27.34, *p*<.001). Bargraph gauges (704ms) were more visually distracting than pointer gauges (642ms; *F*(1,17) = 15.67, *p*=.001). The three-way interaction was significant (*F*(1,17) = 8.24, *p*=.011), and Tukey HSD post-hoc test reported that task 2 implied longer eyes off road duration with Gauge 4 (769ms) than with five other gauges (Gauge 1: 675ms, *p*=.044; Gauge 3: 673ms, *p*=.037; Gauge 5: 553ms, *p*<.001; Gauge 6: 658ms, *p*=.013; and Gauge 7: 665ms, *p*=.021). On the contrary, Gauge 5 was less visually distracting than all other gauges (Gauge 1: *p*=005; Gauge 2: 706ms, *p*<.001; Gauge 3: *p*=.006; Gauge 4; Gauge 6: *p*=.018; Gauge 7: *p*=.011; and Gauge 8: 683ms, *p*=.003).

For the **task 3**, the effect of the indicator was significant: pointer gauges (562ms) were less distracting than bargraph gauges (637ms; *F*(1,17) = 25.59, *p*<.0001). The two-way interaction orientation*indicator was also significant (*F*(1,17) = 4.75, *p*=.044), showing that the effect of the indicator is more pronounced for vertical (vertical-pointer gauges: 554ms, vertical-bargraph gauges: 654ms; *p*<.001) than for horizontal gauges (horizontal-pointer gauges: 571ms, horizontal-bargraph gauges: 621ms; *p*=.033).

3.3 *Satisfaction*

Pairwise comparisons were led for each attribute using Wilcoxon tests (Figure 5a). Globally, circular gauges (mean score: 11.17) are preferred to linear gauges (4.10; Z=3.223, p=.001). Similarly, horizontal gauges (9.04) are preferred to vertical gauges (6.22; Z=3.462, p=.001). Friedman test reported significant differences between gauges ($\chi^2(7)$ = 70.70, p<.001). A hierarchical cluster analysis enables to gather the 8 gauges into clusters which would correspond to different satisfaction levels (Figure 5b). Three clusters resulted from the analysis: a first cluster with the highest satisfaction level (Gauge 1: mean score: 13.11; Gauge 2: 13.17; Gauge 3: 9.87; and Gauge 4: 9.17); a second cluster with a mid-satisfaction level (Gauge 5: 5.70; and Gauge 6: 5.37); a third cluster with the lower satisfaction level (Gauge 7: 2.48; and Gauge 8: 2.94). For the three tasks, similar satisfaction results were found. The effect of the shape was significant (task 1: respectively 11.17 and 4.10, Z=3.223, p=.001; task 2: 11.39 and 4.22, Z=3.092, p=.002; task 3: 11.43 and 4.06, Z=3.593, p<.001), such as the effect of orientation (task 1: respectively 9.04 and 6.22, Z=2.548, p=.011; task 2: 9.38 and 6.24, Z=2.417, p=.016; task 3: 9.60 and 5.89, Z=3.332, p=.001). The satisfaction scores of the eight gauges were significantly different (task 1: $\chi^2(7)$ = 42.55, p<.001; task 2: $\chi^2(7)$ = 41.65, p<.001; task 3: $\chi^2(7)$ = 53.93, p<.001) with the same repartition of gauges into the three clusters that for the global results presented above.

4. Discussion

Based on these results, answers to the research questions are listed below.

4.1 *Does gauge design impact efficiency, distraction and satisfaction?*

Findings showed that gauge design has an impact on task completion times, eyes off-road duration, and satisfaction (gap of visual distraction up to 280ms between two gauge designs). However, no impact was found in term of accuracy of reading. Satisfaction and objective results were inconsistent. For instance, drivers reported a clear preference for circular gauges even if little difference of performance was found between circular and linear gauges. Similarly, Gauge 4 (circular-vertical-bargraph) was part of the higher satisfaction cluster, even if its performance measures were lower than for other gauges. On the contrary, Gauge 5 (linear-horizontal-pointer) implied good objective results and was part of the mid-satisfaction cluster. Driver preference could rely on other factors such as aesthetics or familiarity (Kurosu & Kashimura, 1995).

4.2 *What attributes really matter in gauge definition?*

The shape of the gauge had a high impact on satisfaction. Circular gauges were clearly preferred by drivers compared to linear gauges. However, the shape was not determining on objective measures. An effect of the shape was only found for the qualitative reading (Task 2), with a low impact on task completion (gap of 47ms – 4%) and eyes off-road times (gap of 66ms – 9%). The superiority of circular gauges on linear gauges was also observed in previous researches (Carveth & Adams, 1964; Graham, 1956; Green, 1988; Sleight, 1948). Mayer and Laux (1992) reported however no effect on detection reaction times, but an impact on the primary task. It would then be interesting to confirm these results with driving performance measures.

The orientation of the gauge had a more significant impact on objective criteria. Horizontal gauges were more efficient and less visually distracting than vertical gauges (gap of 126ms – 10%). Moreover, horizontal gauges were greatly preferred by drivers. These results, consistent with previous findings (Graham, 1956; Murrell, 1965; Sleight, 1948), have been explained by physiological reasons. Indeed, the visual field being wider than taller, horizontal eye movements would be easier than vertical ones (Green, 1988).

The indicator type had a low implication in gauge efficiency (gap of 50ms – 3%) and distraction (gap of 65ms – 8%). Connell (1950) proposed that the surface of the indicator would help detection, which could explain the benefit of a pointer against a bargraph. Indicator was also not decisive in drivers' order of preference.

4.3 *Which kinds of gauge displays are best for specific tasks?*

For gauges requiring quantitative reading (Task 1; e.g. tachometer), horizontal gauges were more efficient and less distracting. Eyes off-road duration was decreased by 126ms (10%) compared to vertical gauges. The indicator type also impacted visual distraction, but less significantly, with an eyes off-road duration decreased by 65ms (5%). Linear-vertical-pointer gauges (Gauge 7) should be avoided, considering that they implied a visual distraction increase by about 280ms (20%) compared to other gauge design (Gauge 1: circular-horizontal-pointer or Gauge 5: linear-horizontal-pointer should be preferred). This difference is particularly significant, considering that 280ms

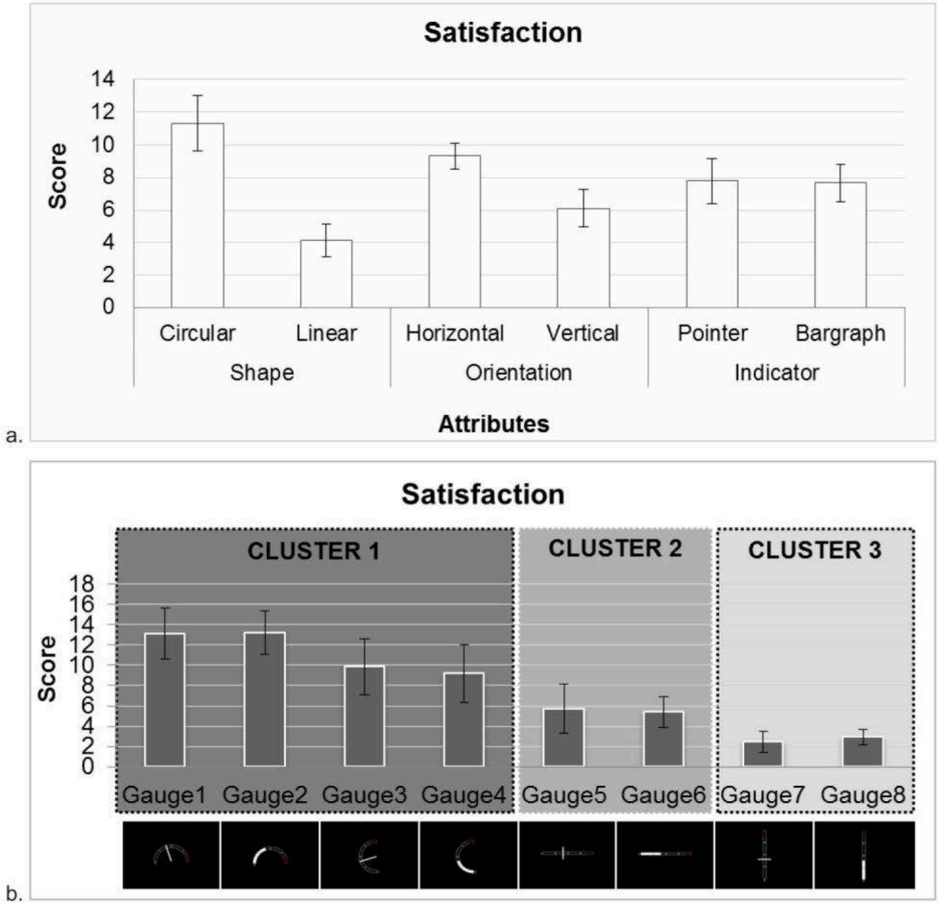

Figure 5. a. Mean satisfaction scores for the three gauge attributes (regardless the task performed)

b. Mean satisfaction score per gauge (regardless the task performed), rectangles represented gauges clusters from the hierarchical cluster analysis.

represents a driven distance of 7 meters at 90km/h.

For gauges requiring qualitative reading (Task 2; e.g. fuel gauge), effects of attributes were less substantial. Linear gauges were more efficient and less distracting than circular gauges, with a reduction of eyes off-road duration by 66ms (9%). Pointer indicators implied a distraction decrease of 62ms (9%), and horizontal gauges of 49ms (7%). Moreover, the gauge combining these attributes clearly marked out (Gauge 5: linear-horizontal-pointer gauge). Significant gains (between 100ms and 210ms – 16% and 29%) were measured in term of distraction. On the contrary, circular-vertical-bargraph gauges (Gauge 4) should be avoided for this task, considering that Gauge 4 was less efficient and more distracting than four other gauge designs (eyes off-road duration increased by 124ms in average – 16%).

For gauges requiring check reading (Task 3; e.g. engine cooling temperature gauge), pointer indicators were more efficient and less distracting than bargraph indicators (visual distraction decreased by 75ms – 12%). The differences between gauges did not match significance, showing that gauge design would be less impacting for this task.

4.4 Limitations and perspectives

This study contributes to the current knowledge on this topic, by adding satisfaction data, and by deepening evidence on the role and weight of different design attributes on information processing. However, future research should address further issues. First, no meaning (e.g. oil pressure) was assigned to the values displayed. Thus, the resulting requirements can be applied to new natures of gauges. Nevertheless, gauges can be symbolic or pictorial (i.e. graphical resemblance with the conditions represented). Another widely acknowledged human factor principle is to support driver's mental model of reality (Ross et al., 1996). For example, the gauge displaying fuel level can be considered as an analogy of the fuel tank. Based on this principle, fuel gauges would be best vertically, even if vertical gauges were found less efficient in this study. Appropriate trade-offs between competing requirements should be assessed according to the nature of the gauge.

Second, gauges were assessed individually on each of the three reading tasks. In a vehicle, the same gauge can be used for different reading. For instance, the gauge of air pressure could be used to judge the rate of increase at starting up (i.e. qualitative reading), to set the pressure at a specific value (i.e. quantitative reading), or to ensure that the system is not impaired (i.e. check reading). The requirements for these different uses may conflict, and it will be necessary to evaluate which is the main reading task (based on relevancy for driving, criticality, urgency, and frequency of use criteria).

Third, gauges were here presented in isolation for finer experimental control. Reading can yet be affected by the layout and the clutter of the cluster. High information clutter may cause overload, increased errors, and difficulties in finding appropriate information (Stevens, Quimby, Board, Kersloot, & Burns, 2002). Gauges may also be operated interdependently (e.g. speedometer and tachometer readings) and the arrangement of multiple gauges has been showed relevant (Green, 1988; Warrick & Grether, 1948). A perspective would be to evaluate if each gauge of a truck dashboard should be designed according to its main reading type (based on the results of this study), or if consistency should be applied. Mayer and Laux (1992) provided a start of an answer reporting that combining dissimilar designs would not make it harder to detect critical values on one gauge.

5. Conclusions

Gauges are major components of trucks dashboards, with direct safety considerations. It is therefore essential to deliver design requirements to practitioners with the following objectives: provide the information in a quick and accurate way to the driver, and minimize eyes-off-road duration. With the arrival of digital instrument clusters, the human factors literature presents only limited answers to contemporary concerns. This experiment updated existing literature and deepened knowledge on the design attributes impact on gauge information processing. The findings of this paper have direct design implications for surface vehicles dashboards: globally, horizontal gauges and pointer indicators should be favoured and circular gauges are preferred by drivers; gauges requiring quantitative reading should be horizontal and linear-vertical-pointer gauges should be avoided; gauges requiring qualitative reading should be linear and circular-vertical-bargraph gauges should be avoided; gauges requiring check reading should have pointer indicators. The linear-horizontal-pointer gauge performed well on all reading tasks (see Gauge 5, Figure 2).

Acknowledgement

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Key points

- Different gauge designs are best for different reading tasks
- Horizontal gauges and pointer indicator are more efficient and less visually distracting
- Circular and horizontal gauges are preferred by truck drivers
- For quantitative reading, eyes off-road time can be decreased by 280ms by changing the design of a gauge

References

Akamatsu, M., Green, P., & Bengler, K. (2013). Automotive technology and human factors research: Past, present, and future. *International Journal of Vehicular Technology*, *2013*.

Baker, C. A., & Grether, W. F. (1954). *Visual presentation of information*. (WADC Technical Report 43064). Wright-Patterson AFB, OH: Wright Air Development Center.

Bedinger, M., Walker, G. H., Piecyk, M., & Greening, P. (2015). 21st century trucking: A trajectory for ergonomics and road freight. *Applied Ergonomics*, *53,* 343–356.

Carveth, J. W., & Adams, J. A. (1964). Effects of practice on dial reading.*Human Factors: The Journal of the Human Factors and Ergonomics Society*,*6*, 81-85.

Chapanis, A. (1960). *On Some Relations Between Human Engineering, Operations Research and Systems Engineering* (report 8). Baltimore, MD: The Johns Hopkins University, Psychology Department.

Connell, S.C. (1950). *Some Variables Affecting Instrument Check Reading* (WADC Technical Report 6024). Wright-Patterson AFB, OH: Wright Air Development Center.

Dillon, A. (1992). Reading from paper versus screens: A critical review of the empirical literature. *Ergonomics*, *35*, 1297-1326.

Endsley, M. R. (1988). *Situation awareness global assessment technique (SAGAT).* Paper presented at the National Aerospace and Electronic Conference (NAECON), Dayton, OH.

François, M., Crave, P., Osiurak, F. Fort, A., & Navarro, J. (2016). *Digital, analogue, or redundant speedometer for truck driving: impact on visual distraction, efficiency and usability*. Manuscript submitted for publication.

François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2016). Automotive HMI design and participatory user involvement: Review and perspectives. *Ergonomics*. Advance online publication.

Graham, N.E. (1956). The Speed and Accuracy of Reading Horizontal, Vertical, and Circular Scales, *Journal of Applied Psycholog, 40,* 228-232.

Green, P. (1984). *Driver understanding of fuel and engine gauges* (No. 840314). SAE Technical Paper.

Green, P. (1988). *Human factors and gauge design: a literature review* (No. UMTRI-88-37). The University of Michigan Transportation Research Institute.

Grether, W.F. (1949). Instrument reading I: the design of long scale indicators for speed and accuracy of quantitative readings. *Journal of Applied Psychology, 33*, 363-372.

Grether, W.F., & Connell,S.C. (1948). *Psychological factors in check reading of single instruments* (WADC Technical Report 4803). Wright-Patterson AFB, OH: Wright Air Development Center.

Kappauf, W.E. (1951). *Design of Instrument Dials for Maximum Legibility: Part 5. Origin Location, Scale Break, Number Location, and Contrast Direction*, (WADC Technical Report 6366). Wright-Patterson AFB, OH: Wright Air Development Center.

Kurosu, M. & Kashimura, K. (1995). Apparent Usability vs. Inherent Usability: Experimental analysis on the determinants of the apparent usability. *Proceedings ACM CHI95 Conference* (pp. 292-293), New York: ACM Press

Mangen, A., Walgermo, B. R., & Brønnick, K. (2013). Reading linear texts on paper versus computer screen: Effects on reading comprehension. *International Journal of Educational Research*, *58*, 61-68.

Mayer, D. L., & Laux, L. F. (1992). Evaluating Vehicle Displays for Older Drivers. *AAA Foundation for Traffic Safety*.

Murrell, H. (1965). Design Factors III. Design of Instrumental Displays. In *Ergonomics: Man in His Working Environment* (pp. 154-215). Netherlands: Springer.

Olsen, A. (2012). The tobii i-vt fixation filter. *Tobii Technology*.

Ross, T., Midtland, K., Fuchs, M., Pauzie, A., Engert, A., Duncan, B., Vaughan, G., Vernet, M., Peters, H., Burnett, G., & May, A. (1996). HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by ATT Systems.

Sanders, M. S., & McCormick, E. J. (1993). *Human factors in engineering and design*. New York: McGraw-Hill.

Sleight, R. B. (1948). The effect of instrument dial shape on legibility. *Journal of Applied Psychology*, *32*, 170.

Stevens, A., Quimby, A., Board, A., Kersloot, T., & Burns, P. (2002). *TRL - Design guidelines for safety of in-vehicle information systems*.

Warrick, M.J.,& Grether, W.F. (1948). *The Effect of Pointer Alignment on Check Reading of Engine Instrument Panels* (WADC Technical Report 69417). Wright-Patterson AFB, OH: Wright Air Development Center.

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2.4. Concept design

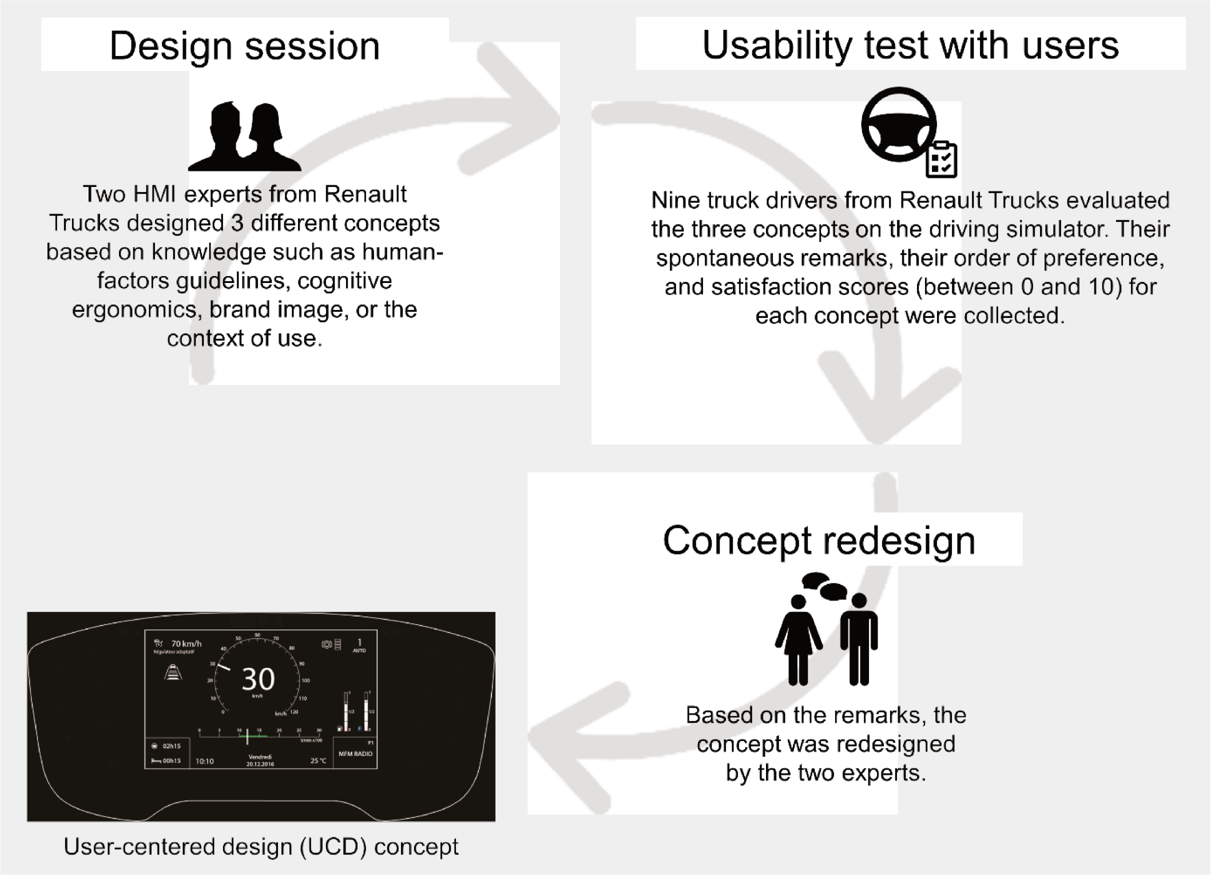
Based on the data collected in the first sub-project and in the studies on human-factors guidelines, the user-centered design was carried out. The process exposed in this part is one of the three parallel processes leaded in this project. The outcome of this design process was evaluated in sub-project 3.

2.4.1. Objectives

A user-centered design process was conducted to provide an outcome corresponding to a consultative involvement (i.e. drivers evaluate concepts designed by experts).

2.4.2. Method

The sub-project 1 and the previous works on ergonomic recommendations was used as input for the design session (Fig. 5).



Two HMI experts from Renault Trucks designed 3 different concepts based on knowledge such as human-factors guidelines, cognitive ergonomics, brand image, or the context of use.

Nine truck drivers from Renault Trucks evaluated the three concepts on the driving simulator. Their spontaneous remarks, their order of preference, and satisfaction scores (between 0 and 10) for each concept were collected.

Based on the remarks, the concept was redesigned by the two experts.

Figure 5: Steps to define the user-centered design concept

Experts defined three concepts based on human factors guidelines, cognitive ergonomics literature, and their knowledge on truck drivers and usages. For this, they used the equipment described in sub-project 2-1.2 during a four-hours design session. After that, nine drivers were involved to assess the three concepts. They could drive on the driving simulator with each concept on a straight road and without specific instruction or task to complete. Their spontaneous remarks, their order of preference, and satisfaction scores (between 0 and 10) for each concept were collected. Based on these data, experts redesigned a final concept.

2.4.3. Highlights and application

The resulting redesigned concept (UCD concept) was compared to the two participatory design concepts in the third sub-project. The UCD concept is described in more details in Paper V.

3. Participatory design

Two participatory processes were conducted with two different methods (one collective and one individual) on the same design case (instrument cluster) and with the same tool than the user-centered design. First, the global methodological considerations prior to participatory design implementation are described. Second, the participatory workshop method (collective) is presented. Finally, individual participatory design sessions method is exposed.

When planning the participatory design sessions, methodological decisions were made on different aspects:

- The objective: To produce instrument clusters concepts.
- The selection of users: For the users involved to be representative of the end-users, the characteristics of the users defined in the first sub-project were used as selection criteria. All drivers were French, they were selected based on their activity (city or regional distribution), age (between 18 and 66 years old) and gender (men). They were recruited as temporary workers.
- The number of stakeholders: To avoid an imbalance situation, the number of users involved was equal to or greater than the number of designers. Regarding the number of users involved in the workshop, as reported by Sanders et al. (2010), participatory design sessions can be conducted with either individuals or with people in groups. The group size can vary from two to many users. Moreover, within the group situation, participants can

work either individually or collectively. They stated that innovation would occur better in a collaborative generation activity. In this research, the two scenarios were tested: collective and individual participatory design. These two methods involve very different resources (i.e. cost, time) and it seemed interesting to evaluate the differences in terms of outcomes.

- Stakeholders roles: 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 thesis, 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).
- The location: Participatory workshops can take place in a professional site, in users’ context of use, in a neutral place, on-line, etc. In our case, the constraint of the equipment was decisive to determine where to conduct the participatory workshops. The location was a spacious room at the company, with a part with tables for group work and a part with the driving simulator and the prototyping tool (Fig. 6).
- The duration: Workshops can be led in one long session, or in many short ones with days of break in between. For practical reasons (costs, drivers’ recruitment for one day), we decided to conduct the workshop in one session with breaks. It allowed drivers to have time to think about and to limit tiredness.
- Activities: 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.
- The ambiance: As in any workshop, attitudes and social aspects should also be considered carefully. For example, a negative or constrained attitude could prevent free and spontaneous expression from users. One of the rules expressed at the beginning of the workshops was thus to address others as “tu” (informal form of “you” in French), and calling by first names (name tags on the tee-shirts). No physical distinction was made between designers and users (e.g. no “staff” shirts). Designers had a role of facilitators, and thus were asked to encourage the expression of ideas and never to bully or negatively judge what was said. Moreover, at the beginning of the session, a time was spent to get to know and “break the ice”, with a convivial introduction around a coffee.

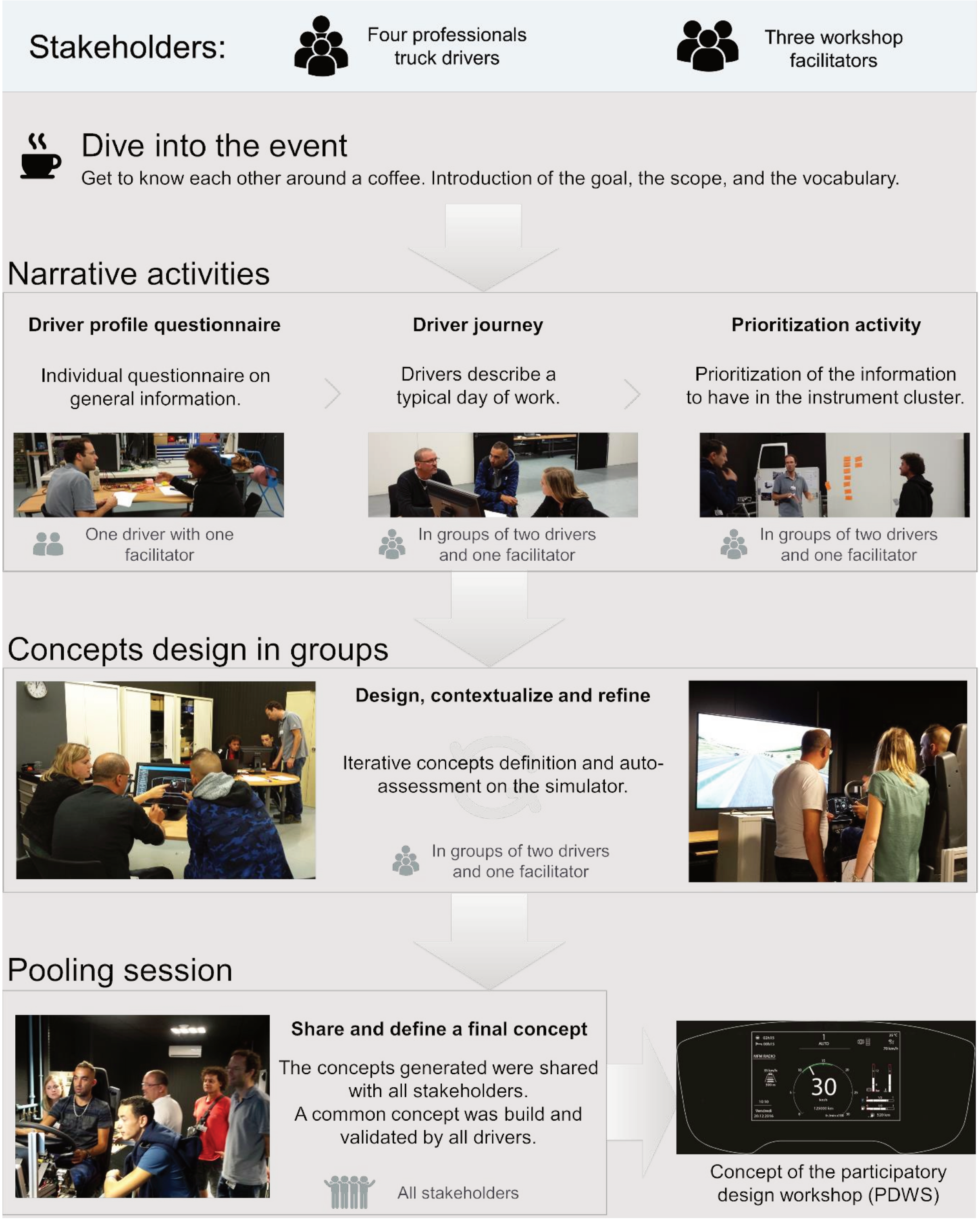
Figure 6: Room of the workshops

3.1. Participatory workshop

The participatory workshop was one of the participatory methods experimented in this research.

3.1.1. Objectives

The participatory design workshop was conducted to provide an outcome corresponding to a participatory involvement (i.e. drivers generate concepts and evaluate them) (Fig. 7). Workshop with several users is a method widely used in participatory design (e.g. Cinto, Ávila, & De Souza, 2015; Dickinson, Lochrie, & Egglestone, 2015; Khaled & Vasalou, 2014; Lamas, Burnett, Cobb, & Harvey, 2015; Lindsay, Jackson, Schofield, & Olivier, 2012; Palaigeorgiou, Triantafyllakos, & Tsinakos, 2011). The advantage of workshops in groups would rely on consensus building and collective intelligence (Sanoff, 2007).



Stakeholders: Four professionals truck drivers; Three workshop facilitators

Dive into the event

Get to know each other around a coffee. Introduction of the goal, the scope, and the vocabulary.

Narrative activities

Driver profile questionnaire

Individual questionnaire on general information.

One driver with one facilitator

Driver journey

Drivers describe a typical day of work.

In groups of two drivers and one facilitator

Prioritization activity

Prioritization of the information to have in the instrument cluster.

In groups of two drivers and one facilitator

Concepts design in groups

Design, contextualize and refine

Iterative concepts definition and auto-assessment on the simulator.

In groups of two drivers and one facilitator

Pooling session

Share and define a final concept

The concepts generated were shared with all stakeholders.
A common concept was build and validated by all drivers.

All stakeholders

Concept of the participatory design workshop (PDWS)

Figure 7: Steps to define the participatory design workshop concept

3.1.2. Method

Four professional truck drivers and three HMI practitioners participated in the workshop. During this workshop, different activities were led: narrative activities, concept design in groups, and a pooling session at the end. During the design activities, drivers iteratively designed and drove on the driving simulator to assess the concept.

3.1.3. Highlights and application

The resulting concept was compared to the two other concepts in the third sub-project (PDWS concept). This participatory concept is described in mode details in Paper V.

3.2. Individual participatory design sessions

Individual participatory design sessions was the second participatory method experienced during this thesis.

3.2.1. Objectives

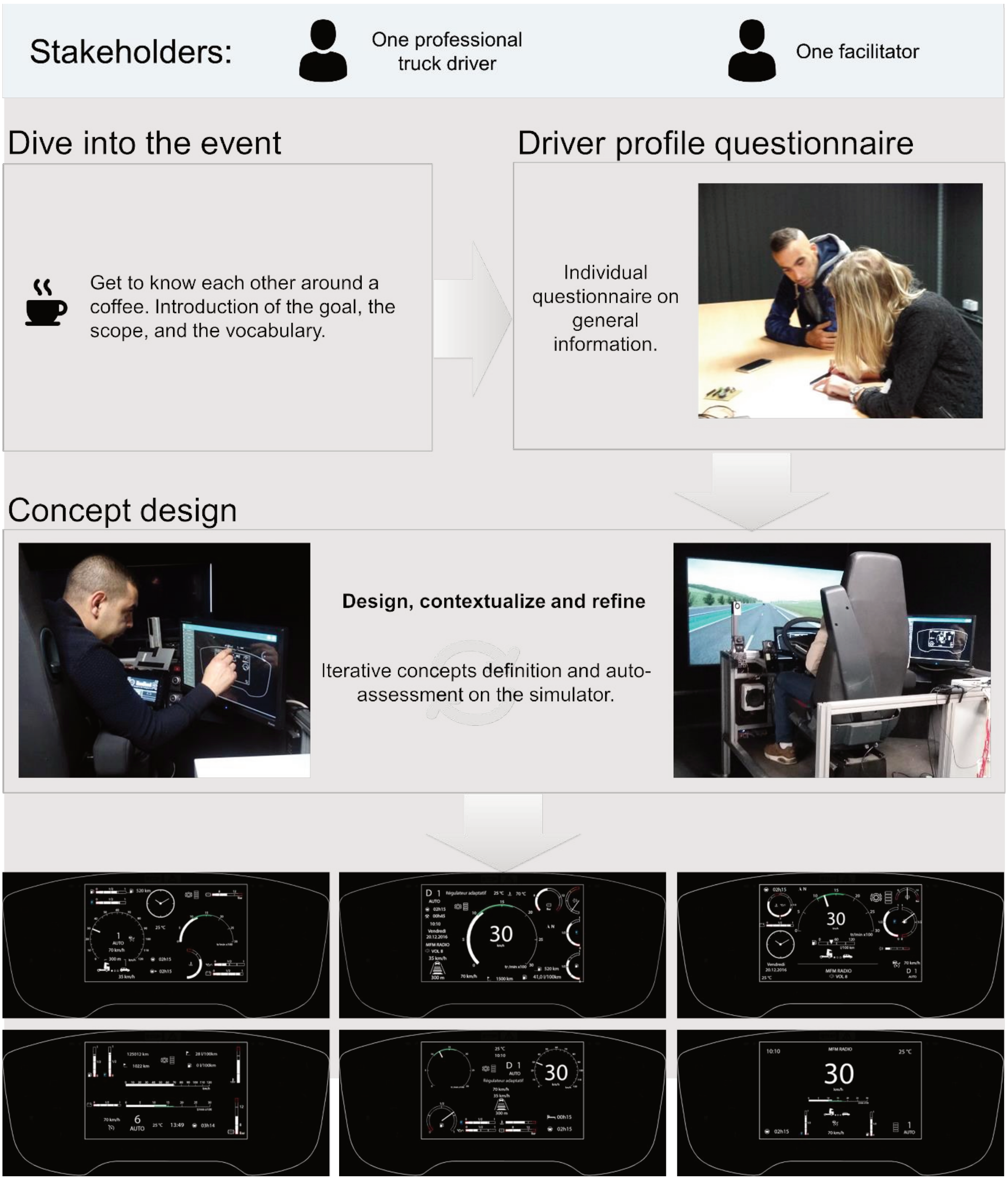
Individual participatory design sessions were conducted to provide an outcome corresponding to a participatory involvement, in which drivers generate concepts and evaluate them individually.

3.2.2. Method

In total twenty-seven truck drivers participated in individual sessions (Fig. 8). Drivers were different from those who attended the participatory workshop. During the design session, each driver was with a facilitator. After a narrative activity, the driver could move to the driving simulator and define his concept while evaluating it iteratively in a free driving situation.

3.2.3. Highlights and application

The resulting concept (PDInd concept) was compared to the two other concepts (UCD and PDWS concepts) in the third sub-project. This participatory concept is described in mode details in Paper V.



Get to know each other around a coffee. Introduction of the goal, the scope, and the vocabulary.

Individual questionnaire on general information.

Iterative concepts definition and auto-assessment on the simulator.

Six examples of participatory design individual concepts (PDInd) on the twenty-seven collected

Figure 8: Steps to define the participatory design individual concepts

Sub-project 3: Concepts assessment

During the second sub-project, three concepts of instrument clusters were designed, according to three different design processes. In this third sub-project, the goal was to assess and compare rigorously these three concepts.

1. Objectives

The aim of this sub-project was to evaluate and compare the three concepts of instrument cluster in terms of usability, distraction and acceptance. Indeed, there is a trend for more and more user involvement in design, but with a lack of empirical and rigorous evidence in favor of this. Moreover, some benefits are addressed globally to participatory design whatever the method implemented, although there are significant differences between them.

2. Method

Twenty-seven truck drivers were asked to perform eleven different tasks in a simulated drive to compare the three concepts of trucks instrument clusters (the UCD concept, the PDWS concept, and their own concept defined the same day in the individual participatory design session).

3. Highlights and application

Paper V and VI respectively subjective findings (perceived usability and acceptance) and objective data (efficiency and distraction obtained within this sub-project. On the subjective side, 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. On the objective side, the concept generated with the UCD process implied lower task completion and eyes-off-road times than both PD outcomes.

These findings question PD benefits and encourage focusing more on the different PD approaches.

Paper V

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

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

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Previous literature reported that Participatory Design (PD) results in more satisfying products and presents other subjective benefits. PD implies an active involvement of users during all steps of the design process, including during concepts design (contrary to user-centered design). This study investigates whether PD could improve usability and acceptance of trucks dashboards, and whether subjective benefits would be preserved whatever the participatory approach implemented. Two PD approaches were led on the same design case and with the same equipment: a participatory workshop and individual design sessions. The concepts resulting from these two approaches were assessed and compared to a concept generated by HMI experts in a user-centered design process. 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 focusing more on the different PD approaches.

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

1. Introduction

On trucks 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), function feedbacks (e.g. turn signal indicator light), or mechanical issues (e.g. telltales, alerts). When designing a new instrument cluster, some human factors considerations have to be taken into account in order 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 to display them, and specifying a logic of interaction. The major consideration when designing truck instrument cluster is that this interface will mainly be used while driving (Marcus, 2004). In this dual task situation, every interaction with the cluster can create interference 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. Indeed, 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 constructs: 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 errors (i.e. errors); and using the interface should be pleasant (i.e. satisfaction). This notion of usability is very close to the concept 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 of two factors: perceived usefulness and perceived ease of use. For example, a driver could neglect a system that he would not need, or if he would have too much difficulty 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 trucks' instrument clusters. 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 its satisfaction in use became determinant (Marcus, 2004). Different factors are challenging usability and acceptance during trucks interfaces design. First, information number and complexity 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 are a broad range of truck drivers in terms of experience level, motivation, age, expertise, emotional status, time pressure, relation to technology, etc. Moreover, regarding environment factors, there are 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, tanker, moving trucks). Finally, instrument clusters in vehicles become display screens bringing with them dynamic and flexibility, but also many possible 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), concept design (produce design solutions to meet user requirements), and concept 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 different 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 surveys, interviews, observations, activity analysis, etc. 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). 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 design by experts)
- Participatory design (PD) would imply a participative involvement (users are involved during analyses and assessment phase, but also to 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 allow considering interface usability and users' needs and expectations. 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 (Carroll & Rosson, 2007). 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 silent 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. 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 have 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 or virtual reality (Bruno & Muzzupappa, 2010) 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; Palaigeorgiou, Triantafyllakos, & Tsinakos, 2011). 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 (International HIV/AIDS Alliance, 2001). 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.

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 two levels of driver involvement: user-centered design (UCD) and participatory design (PD). Two participatory approaches were experimented: a participatory workshop, and individual design sessions. 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.

The following research questions are raised:

- RQ1: Does the level of driver involvement influence usability and acceptance of instrument clusters?
- RQ2: Is there a usability and acceptance gap between what a driver has defined for him, and what other drivers have defined for him?

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 individual sessions, each driver defined a concept by himself

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

2.1. Equipment

Concept generation was made using specific software on a touchscreen. The touchscreen was installed on a fixed-base medium-fidelity driving simulator to allow iterative driving during concepts design (Fig. 1). The software, as a 'make tool', was developed especially for this study in order to define all concepts with the same equipment. It was developed with Adobe Flash, 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 (Fig. 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 he wants to display. The selected widget appears 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. 17 functions categories were presented, with a total of 186 different available widgets. The background, size and shape of the stage were imposed (Fig. 1). It consisted in a kind of Booth oval form including in the center an 8 inches surface and telltales around (white and black). The goal was to simulate an oval hardware containing telltales, and a screen instrument cluster of 8 inches. Users were allowed to arrange widgets in the 8 inches screen surface only.

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).

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. 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, he could choose a widget that was displayed on the stage. He could then change his size and location.

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

2.2.1. Participants

A concept has been 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. They both had more than 10 years at Renault Trucks working at 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 activities in the past to increase their knowledge on truck drivers' activities and needs (e.g. surveys, activity analyses, and focus groups).

2.2.2. Procedure

The two experts were first invited for one design session of 4 hours. A list of mandatory functions to display was made available to them: speed, gearbox information (mode and lever position), retarder, mode and target speed of the ADAS. 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 0 and 10) 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. Concept description

After redesign, the UCD concept contained 23 widgets (including 4 graphical separators; Fig. 2). The size of 16 widgets was modified by designers (5 of them were made bigger and 11 smaller). To give an idea of the visual density of the concept, the percentage of white was 10.60%.

The human factors design principles were applied. 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 tip 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). 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 4 drivers

2.3.1. Participants

4 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. They 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 1 year and more than 10 years. All reported normal or corrected-to-normal vision. All of them were used to interact with a smartphone.

3 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. Both of them were the HMI experts that defined the UCD concept.

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

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

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 we 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 in 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 on the typical day of a truck driver. Facilitators asked drivers to describe a typical day from getting up on the morning to getting to bed at night. A particular focus was put on the use of trucks HMI at each step the day. Second, an activity of prioritization of information was made. Here, focus was put 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. After the spontaneous generation, drivers grouped the sticky notes on the wall in three groups of perceived importance. For each sticky, a color point is 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 can add information they would have forget. The data gathered from this activity is important knowledge for HMI designers. In addition, the objective of this activity was to concentrate on the information of the instrument cluster and to focus on drivers' needs and expectations. 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 on the touchscreen (on a table in a first time because space was limited around the simulator). They could later upload their concept on the simulator and drive with it. During driving on a highway environment, no specific instruction was given. Drivers could stop at any time, make modification of their concepts on the touchscreen, and resume driving. Each group could produce up to three concepts. They should include mandatory functions (the same as the UCD concept). In facts, 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, but they did not had a role of designer or any influence on drivers' choices.

After lunch, participants were brought together for a 'pool and chose' session. The concepts generated were printed, hang on the wall, and shared with all stakeholders. Each group explained their choices and strategies to the others.

On this basis, a common concept was built by the four drivers on the driving simulator. When they decided that the concept was complete, it was validated by all drivers thanks to a free test-drive.

At the end of the workshop, they were asked to fill individually a feedback questionnaire. Seven points Likert scales measured 4 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), and based on the original questionnaire of Barki and Hartwick (1994). Results showed that drivers felt involved, and were very positive about their participation in trucks' HMI design (involvement: *M*=

5.94/7, *SD*= 1.26; attitude: *M*= 6.06/7, *SD*= 0.68; self-efficacy: *M*= 6.25/7, *SD*= 0.96; desired participation: *M*= 6.75/7, *SD*= 0.5).

2.3.3. Concept description

The PDWS concept contained 22 widgets (including 3 graphical separators; Fig. 3). The size of 7 widgets was modified by drivers (2 of them were made bigger and 5 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'). 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 between the top right corner and the left part of the cluster.

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

2.4.1. Participants

27 truck drivers (all men, mean age: 38 years, SD: 9) participated in individual design sessions. All drivers were different from those who attended the participatory workshop. They were recruited as temporary workers for one day. 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 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. 22% had between 1 and 5 years of professional experience, 37% between 5 and 10 years, and 41% has more than 10 years of experience. All reported normal or corrected-to-normal vision. 89% 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). 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. He could drive at any moment to self-assess his concept on a highway environment and without specific instructions. He should include mandatory functions (the same as the UCD and PDWS concept). When he thought that the concept was completed, a debriefing was conducted with the facilitator in order to collect explanation about his choices.

2.4.3. Concepts description

27 concepts were collected (one per driver; examples in Fig.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). 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 has been 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 ADAS 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. 41% of concepts were organized as the UCD and the PDWS concepts,

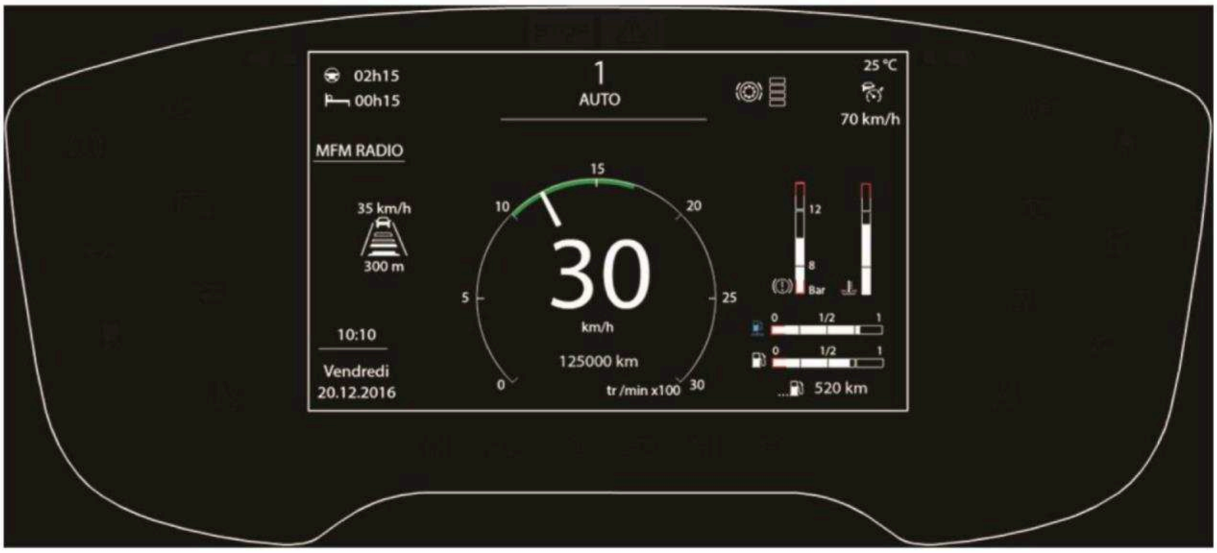

Figure 3. Concept resulting from the participatory workshop (PDWS concept).

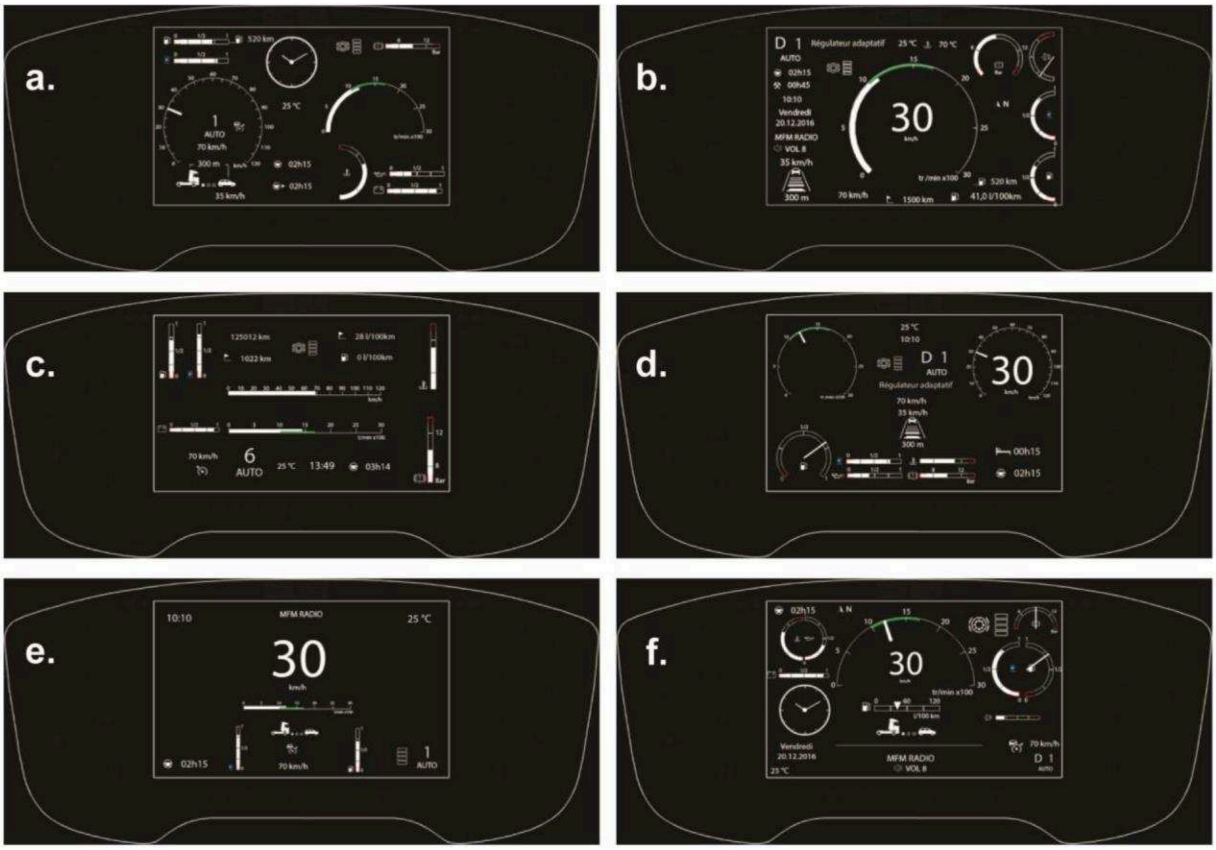

Figure 4. Examples of concept resulting from the individual participatory design sessions (PDInd Concepts).

around centered speed information (e.g. Fig. 4b, 4e and 4f). Second, 26% of concepts were organized around two analogue counters (speed and tachometer) displayed horizontally (e.g. Fig. 4a and 4d). The remaining 33% presented other layout patterns (e.g. Fig. 4c).

3. Step 2: Concepts assessment

3.1. Participants

Participants were the same 27 truck drivers who participated to the individual participatory design sessions. Indeed, drivers were invited for one day. On the morning, they defined their own concept; on the afternoon, they assessed their concepts against both UCD and PDWS concepts. All drivers were different from those who attended the participatory workshop.

3.2. Equipment

The assessment was led on the same driving simulator than 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^{TM} 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: 1280x800).

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 he defined the same morning.

3.3.2. Driving scenario and tasks

Each of the three driving scenarios lasted about 20 minutes. 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. 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. 11 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.

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. Drivers had to tick the graduated line of 150mm to rate their perceived mental effort required (the measurement in mm giving a score on 150). Second, the System Usability Scale was used as a global indication of usability. 10 items from ‘strongly disagree’ to ‘strongly agree’ gave a global score of usability on 100 points. Third, a questionnaire aimed at measuring in more detail the five constructs of usability, as defined by Nielsen (1992). It consisted of a 5 items questionnaire (one per construct: learnability, efficiency, memorability, errors, and satisfaction) with 5 points Likert scales, from ‘1 = strongly disagree’ to ‘5 = 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 10 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 1 to 3) 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 11 point 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 different aspects of satisfaction, usability, and acceptance. Moreover, 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.

3.4. Procedure

Participants spent the half of the day designing their own concept before this phase. The assessment started after a long 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 10 min trial, in order 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 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 each participant experienced all conditions. The

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

Task number	Task instruction	Expected answer
1	Which is the gear engaged?	Verbal answer: e.g. 5
2	How fast do you drive?	Verbal answer: e.g. 45 km/h
3	Do you still have at least 1/4 of gasoline?	Verbal answer: yes or no
4	Set the radio station to ...	Action: turn the thumbwheel until reaching the required station
5	Do you drive above or below 30 km/h?	Verbal answer: yes or no
6	Set your cruise control to 70 km/h.	Action: activate the cruise control, set the target speed with plus and minus switches
7	Set your speed limiter to 50 km/h.	Action: activate the speed limiter, set the target speed with plus and minus switches
8	Is the retarder activated?	Verbal answer: yes or no
9	What is your driving time?	Verbal answer: e.g. 3h02
10	What time is it?	Verbal answer: e.g. 14h45
11	Is the speed limiter activated?	Verbal answer: yes or no

order in which the experimental condition were presented was counterbalanced by following a Latin square crossing the three concepts. The total test duration was approximately three hours.

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. Pairwise comparisons were performed using Wilcoxon tests (Fig. 5). Perceived mental effort was statistically significantly different between the three concepts, χ^2 (2) = 11.370, *p*= .003. Post hoc analysis revealed statistically significant differences in RSME scores between UCD (*Mdn*= 26) and PDWS concepts (*Mdn*= 38) (*Z*= 3.01, *p*= .003, *r*= 0.41), and between PDInd (*Mdn*= 28) and PDWS concepts (*Z*= 2.34, *p*= .019, *r*= 0.32), but not between UCD and PDInd concepts.

4.1.2. System usability scale

A Friedman test examined differences in SUS scores between the three concepts, and revealed a statistical trend (χ^2 (2) = 4.796, *p*= .091). Usability scores were higher with the UCD concept (*Mdn*= 90) than for the PDWS concept (*Mdn*= 80) (*Z*= 2.45, *p*= .014, *r*= 0.33). Similarly, the PDInd concept (*Mdn*= 87.50) revealed better SUS scores than the PDWS concept (*Z*= 2.37, *p*= .018, *r*= 0.32). The difference between the UCD and the PDInd concepts was not statistically significant.

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. Friedman tests revealed significant differences between the three concepts for all dimensions (learnability: χ^2(2)= 13.000, *p* =.002; efficiency: χ^2(2)= 18.778, *p*< .001; memorability: χ^2(2)= 11.485, *p*= .003; errors: χ^2(2)= 11.855, *p*= .003; and satisfaction: χ^2(2)= 6.583, *p*= .037). The UCD concept was scored significantly better than the PDWS concept on four of the five dimensions (learnability: *M*= 4.44 and *M*= 3.78, *Z*= 2.19, *p*= .029, *r*= 0.30; efficiency: *M*= 4.30 and *M*= 3.44, *Z*= 2.88, *p*= .004, *r*= 0.39; memorability: *M*= 4.56 and *M*= 3.81, *Z*= 2.75, *p*= .006, *r*= 0.37; and errors: *M*= 4.19 and *M*= 3.41, *Z*= 2.79, *p*= .005, *r*= 0.38). On satisfaction, the fifth dimension, the difference between UCD (*M*= 4.07) and PDWS (*M*= 3.59) was not significant but a trend (*Z*= 1.85, *p*= .065, *r*= 0.25). Similarly, drivers scored significantly better the PDInd concept than the PDWS concept on the all dimensions (learnability: *M*= 4.78 and *M*= 3.78, *Z*= 3.28, *p*= .001, *r*= 0.44; efficiency: *M*= 4.48 and *M*= 3.44, *Z*= 3.41, *p*< .001, *r*= 0.46; memorability: *M*= 4.52 and *M*= 3.81, *Z*= 2.58, *p*= .010, *r*= 0.35; errors: *M*= 4.22 and *M*= 3.41, *Z*= 2.77, *p*= .006, *r*= 0.38; satisfaction: *M*= 4.30 and *M*= 3.59, *Z*= 2.35, *p*= .019, *r*= 0.32). No significant difference was found between the UCD and the PDInd concepts.

4.2. Acceptance

4.2.1. Acceptance scale

Friedman tests were run to determine if there were differences of utility and satisfaction between

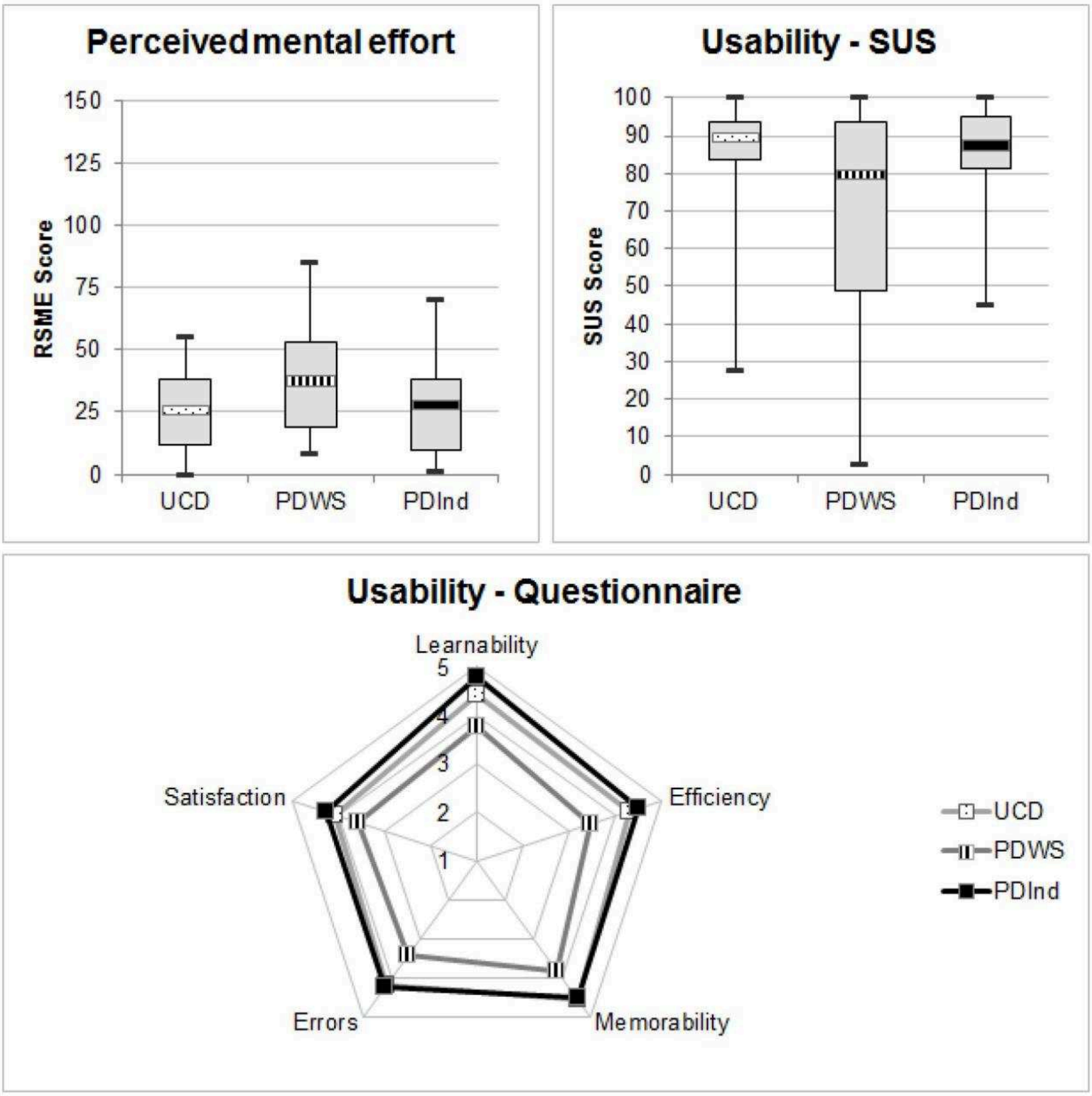

Figure 5. Results to the RSME, System Usability Scale (SUS), and usability questionnaire for the three concepts.

with the three concepts. Pairwise comparisons were performed using Wilcoxon tests. Regarding utility, a statistically significantly difference was found between the three concepts, χ^2 (2) = 8.37, *p*= .015 (Fig. 6). Post hoc analysis revealed a statistically significant difference in utility between PDInd (*M*= 1.29) and PDWS concepts (*M*= 0.64) (*Z*= 3.33, *p*= .001, *r*= 0.45). 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 (χ^2 (2) = 6.61, *p*= .037). Pairwise comparisons showed that the difference between UCD (*M*= 0.98) and PDWS scores (*M*= 0.55) was significant (*Z*= 2.15, *p*= .003, *r*= 0.29), such as the difference between PDInd (*M*= 1.23) and PDWS scores (*Z*= 3.24, *p*= .001, *r*= 0.44). On the contrary, the difference between UCD and PDInd was not significant.

4.2.2. Preference

Regarding the order of preference, 52% of drivers ranked the PDInd concept at the first place (against 33% for the UCD concept and 15% for the PDWS concept). The difference of rank was significant between the three concepts (χ^2 (2) = 7.41, *p*= .025). Pairwise Wilcoxon tests revealed that the order of preference was significantly better for the PDInd concept (*Mdn*= 1) than for the PDWS concept (*Mdn*= 3) (*Z*= 2.52, *p*= .012, *r*= 0.34). Even if the UCD concept (*Mdn*= 2) was better ranked than the PDWS concept and worse than the PDInd concept, differences were not statistically significant.

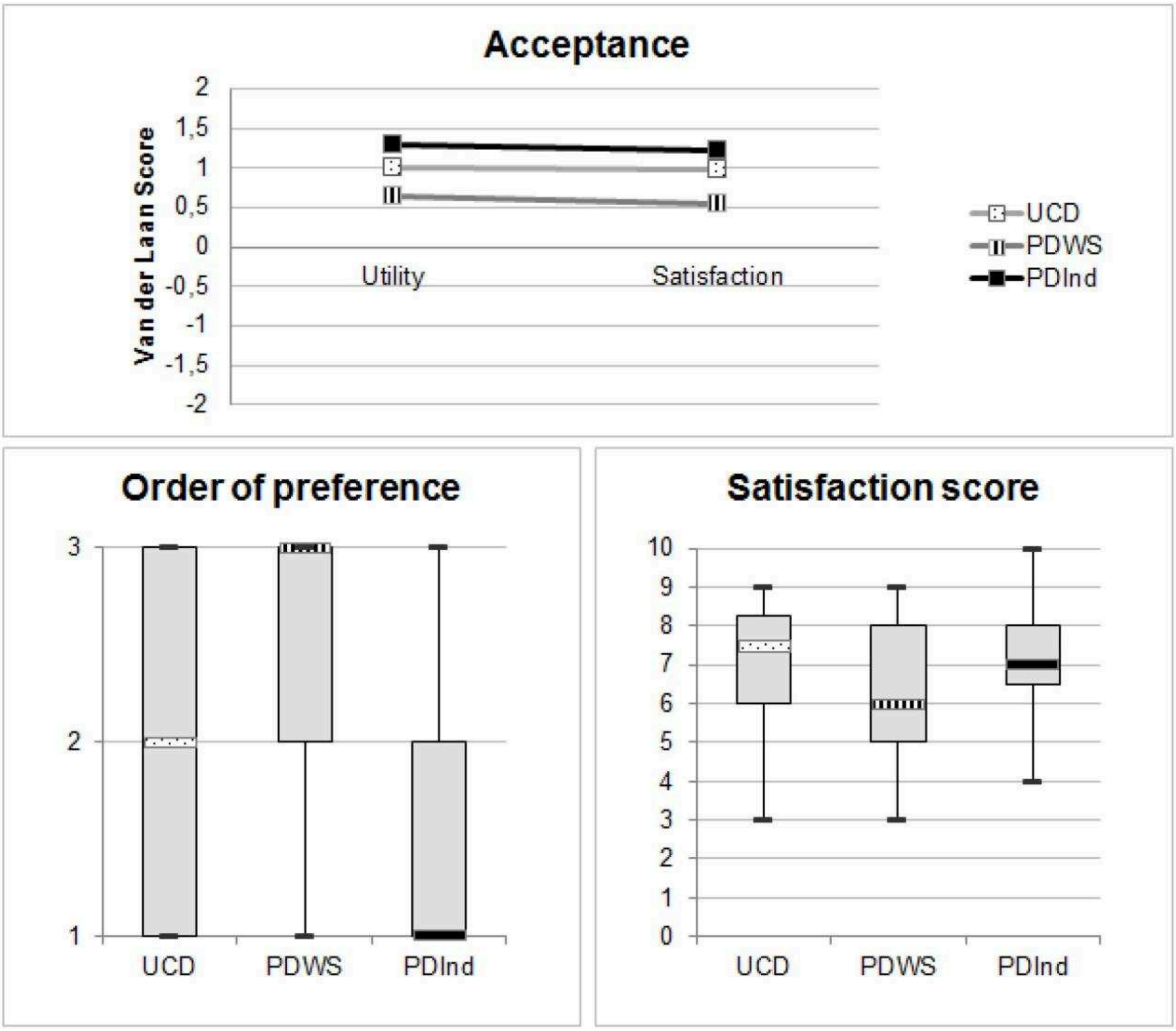

Figure 6. Van der Laan et al. (1997) Acceptance Scale average scores, medians of the order of preference, and medians of the satisfaction scores for the three concepts.

The satisfaction scores (between 0 and 10) were not significantly different between the three concepts (χ^2 (2) = 2.558, p = .278). The UCD concept collected better scores (*Mdn*= 7.5), followed by the PDInd concept (*Mdn*= 7), then by the PDWS concept (*Mdn*= 6).

5. Discussion

5.1. Findings

5.1.1. RQ1: Does the level of driver involvement influence usability and acceptance of instrument clusters?

Based on previous studies, 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 concept with the concept of the participatory workshop, and the user-centered design concept with individual concepts.

Findings revealed that the concept generated with a user-centered design process was perceived as more usable than the concept of the participatory workshop. 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 learnability, efficiency, memorability, and errors. Regarding acceptance, the UCD concept was perceived as more useful and satisfying than the PDWS concept. Even if it was not significant, the UCD concept also collected better 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 33% of drivers (with a slightly higher rating: *Mdn*= 7.5/10). 85% 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 have a good knowledge of 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 what a driver has defined for him, and what other drivers have defined for him?

Results showed a marked difference between the individual concept and the concept resulting from the participatory workshop. On all measurements carried out, the individual concept was perceived as more usable: perceived mental effort was significantly lower and global usability scores were significantly better (such as for each of the five dimensions of usability). Concerning 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 without appeal and constant 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. The participatory workshop did not resulted in a concept meeting the needs and expectations 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 don't always know what they want (Madrigal & McClain, 2011) has been shown to be false. On the contrary, the result 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 'odd users' (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 result (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 input for the design phase by the experts in a UCD (as proposed in the ISO/TR 16982, 2002).

Third, even if findings of this study open perspectives for trucks dashboard personalization, 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. Moreover, 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 6 months after purchase. The usability and acceptance of their concepts could thus have been 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 focusing more on the different PD approaches. Moreover, these results show that a design by experts *for* and *with* users can produce usable and accepted outcomes.

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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.

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.

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.

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.

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 HIV/AIDS Alliance (2001). *A facilitators' guide to participatory workshops with NGOs/CBOs responding to HIV/AIDS*. British Charity Number 1038860.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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Paper VI

Efficiency and distraction of truck dashboards designed by drivers: two participatory design approaches compared to user-centered design

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Efficiency and distraction of truck dashboards designed by drivers: two participatory design approaches compared to user-centered design.

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Objective: The aim of this study was to evaluate and compare three concepts of instrument cluster in terms of efficiency and distraction. The concepts were defined using three design processes differing in level of user involvement (user-centered design [UCD] and two different participatory design [PD] methods).

Background: There is a trend for more and more user involvement in design, but with a lack of empirical and rigorous evidence in favor of this. Moreover, some benefits are addressed globally to participatory design whatever the method implemented, although there are significant differences between them.

Methods: Twenty-seven truck drivers were asked to perform eleven different tasks in a simulated drive in order to compare three concepts of trucks instrument clusters: a concept created in a user-centered design process (defined by HMI professionals 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).

Results: Results showed that the concept generated with the UCD process implied lower task completion and eyes-off-road times than both PD outcomes. Differences of efficiency and distraction were found between the concepts from the two PD methods.

Conclusion: The findings do not support higher efficiency and lower distraction of instrument clusters developed with PD. Additionally, significant differences existed among PD outcomes.

Application: Participatory design for in-vehicle interfaces is challenged. Further research and design efforts are needed to investigate the effect of user involvement on design outcomes.

Keywords: Distraction; HMI design; Interface evaluation; Participatory ergonomics; Commercial vehicles dashboards

1. Introduction

1.1. Trucks dashboards design

On trucks dashboards, the instrument cluster is the main way of communication from the vehicle to the driver, displaying information such as vehicle state, gauges, function feedbacks, or mechanical issues. While designing a new instrument cluster, designers have to face several challenges. The first consideration is of course that the interface will mainly be used while driving. The dual task situation can create interferences with the primary driving task, implying potential road safety issues. Instrument clusters should be designed to minimize cognitive load and eyes-off road time during interaction (Marcus, 2004). Second, information to fit in instrument clusters has increased in number and complexity (Gkouskos, Normark, & Lundgren, 2014). Designers should carefully define which information to present to the driver, how to display it, and specify a logic of interaction that ensure an easy, quick, and error-free access to information. Third, an instrument cluster is designed for a range of trucks, which involves a wide diversity of drivers using it (e.g. different experience level, age, relation to technology), for different activities (e.g. fire trucks, tanker, city delivery), and in various environments (e.g. city, construction areas, highway). The interface must meet the needs of each user in the different contexts of use. Finally, instrument clusters in vehicles become display screens. This enable dynamic and flexibility (Marcus, 2004), but it also brings many layout possibilities that cannot all be tested in classical usability tests.

In order to address these design challenges, professionals focus on three design and assessment criteria: usability, distraction, and acceptance (François, Osiurak, Fort, Crave, & Navarro, 2017a; Harvey, Stanton, Pickering, McDonald, & Zheng, 2011). First, acceptance is defined as the intention to use a system and “to incorporate the system in his/her driving” (Adell, 2009). Drivers’ intention to use a system is closely linked to users’ subjective experience and depends of drivers’ perceived usefulness and ease of use (Davis, Bagozzi, and Warshaw 1989). Second, the usability of an interface defines “how easy user interfaces are to use” (Nielsen, 2012). Usability can be divided in five constitutive aspects: learnability (i.e. ease of learn how to use the interface), efficiency (i.e. amount of resources needed to use the interface), memorability (i.e. ease of remember how to use the interface after a non-use period), errors (i.e. propensity to avoid and recover from errors), and satisfaction (i.e. pleasure to use the interface) (Nielsen, 2012). Finally, a well-designed interface should minimize driver distraction (i.e. physical, visual, and cognitive) to preserve drivers’ ability to perform primary driving tasks while using the instrument cluster (Strayer et al., 2015). Two aspects of these three criteria can be dissociated: the interpretive and subjective aspect, and the objective aspect. On the subjective side, acceptance and perceived usability are based on user perceptions, attitudes, and intentions towards the interface. They are measurable using qualitative data such as questionnaires. From an objective perspective, actual usability and distraction are measurable using quantifiable data such as error rate, user performance, or time taken to complete tasks. Tractinsky, Katz, and Ikar (2000) pointed out that actual and perceived usability can be treated separately as they evolve independently. Both aspects are complementary and fundamental to create a safe and comfortable driver experience.

1.2. User-centered design versus Participatory design

Human-centered design processes include different approaches focusing on the use of a system and applying human factors, ergonomics, and usability knowledge and tools (International Organization for Standardization [ISO] 9241-210, 2010). Three iterative steps are led in a human-centered design process: analysis of the context of use, concept design, and concept assessment. The ISO 9241-210 (2010) highly recommends user involvement during this process. The different human-centered approaches contrast on when and how users are involved. Even if forms of involvement do not have clear boundaries (Damodaran, 1996), two major human-centered approaches can be differentiated (Bekker & Long, 2000; Bratteteig & Wagner, 2016; Carroll, 1996; Kujala, 2003; Sanders, 2002; Spinuzzi, 2005):

- User-centered design (UCD) would imply an *informative* and *consultative* involvement (Damodaran, 1996). Users are involved during the analyses and assessment phases, but concepts are designed by experts. According to the classification of Eason (1995) on user involvement in product design, UCD corresponds to a design *for* and *with* users.
- Participatory design (PD) would imply a *participative* involvement (Damodaran, 1996). Users are involved during the analyses and assessment phases, but also during the concept design phase. This approach corresponds to a design *by* users (Eason, 1995).

The main distinction between the two approaches would then be the involvement of users in the design phase in PD, which is absent from UCD.

On this basis, there are a variety of ways to arrive at a PD outcome (Bratteteig & Wagner, 2016; Sanders, Brandt, & Binder, 2010). During the design sessions, many aspects can vary such as the roles of users and designers (from facilitator to co-designer; Sanders & Stappers, 2008), the ‘make-tool’ used to design (from papers and pencils to interactive prototypes; Sanders, 2002), the type of workshop activities (from telling to enacting activities; Sanders et al., 2010), or the number of users involved in the workshop (in group of individually; Sanders et al., 2010). On this last point, two ideas are facing each other. Participatory workshops in group would benefit from consensus building and collective intelligence (Sanoff, 2007). On the contrary, individual design sessions would enable the elicitation of individual particular needs (Fan & Poole, 2006; Sleeswijk Visser et al., 2005). It is important to investigate the benefits of each method, especially considering that individual design sessions are in line with the trend of customizable products which is becoming increasingly widespread.

1.3. Participatory design: a perspective towards safer and more efficient interfaces

Today, instrument clusters for trucks are mainly defined using user-centered design. Concepts of instrument clusters are defined by HMI professionals based on the previous phase of analyses and on their knowledge (i.e. driver needs, cognitive ergonomics, technical possibilities, project-lead times, brand image, etc.). These concepts are then assessed by drivers before redesign. Nevertheless, two ideas go in the direction of a beneficial shift from UCD towards PD. A ‘moral’ benefit relies on the fact that users would have a right to be involved in decision-making (Carroll & Rosson, 2007). A ‘pragmatic’ benefit would be due to the fact that users’ experience and knowledge can offer insights and increase chances for a successful design outcome (Carroll & Rosson, 2007). Gathering better outcomes compared to a UCD would be based on two rationales. First, users would have implicit needs (i.e. tacit and latent needs) that they could not express only by ‘saying’ or ‘using’ a concept (Sanders, 2002). Only the fact of ‘making’ would allow access to these needs and thus enable an increased acceptance. Second, users would have tacit knowledge engaged when interacting with an interface (e.g. user’s mental models, user’s experiences, procedural skills). PD would elicit this implicit knowledge by incorporating it as a direct resource in the design phase (Spinuzzi, 2005). The resulting outcomes would therefore be more usable and less distracting (Francois et al., 2017a). In this sense, Marcus (2004) suggested that even if customization of a vehicle user interface can be risky due to the criticality of the driving task, it can still be beneficial. He proposed that it would reduce complexity, avoid cognitive and sensory overload, and result in faster and safer tasks completion.

Previous studies in other fields reported several PD benefits, such as an improvement of product quality (Bachore & Zhou, 2009; Damodaran, 1996), better outcomes effectiveness (Kujala, 2003), or a greater understanding of the system resulting in more effective use (Damodaran, 1996). Moreover, in the automotive field, Normark and Gustafsson (2014) reported that car drivers did not feel that driving with a customized cockpit negatively affected their driving. On the other hand, DeSmet et al. (2016) led a meta-analysis reporting that medical serious games would be more effective when designed by professionals and tested by users, than resulting from a PD process.

1.4. Aim and Research Questions

This study follows a previous article based on the same experiment, reporting the results on subjective measures (acceptance and perceived usability) (François, Osiurak, Fort, Crave, & Navarro, 2017b). Findings showed that a concept generated using a participatory workshop (with several users; PDWS) was perceived significantly less usable and accepted than both concepts resulting from user-centered design (UCD) and individual participatory design sessions (PDInd). On the other hand, the UCD concept and the PDInd concepts did not differ in usability and acceptance (high scores for both), even if drivers slightly preferred their own concept.

In the present article, the aim was to evaluate and compare the outcomes from different approaches (UCD, PDWS, and PDInd) in terms of objective measures (actual usability - or efficiency - and distraction). Indeed, there is a trend for more and more user involvement in design (Marcus, 2004; Sanders & Stappers, 2008), but there is a lack of empirical and rigorous evidence in favor of this. There are many evaluations of PD processes (Bossen, Dindler, & Iversen, 2016), but few rigorous evaluations of PD outcomes (Bratteteig & Wagner, 2016). Benefits are often attributed globally to PD, although it is essential to investigate further the different PD methods (François et al., 2017b). Finally, efficiency and distraction of instrument clusters are critical for road safety. It is essential to measure the effects of PD on objective aspects, even more in a perspective of dashboard personalization (Marcus, 2004).

The following research questions were then raised:

- RQ1: Does the level of driver involvement influence efficiency and distraction of instrument clusters?
- RQ2: Is there an efficiency and distraction gap between what a driver has defined for him, and what other drivers have defined for him?

2. Method

2.1. Participants

Twenty-seven truck drivers (all men, mean age: 38 years, SD: 9) were recruited as temporary workers for one day. On the morning, they participated in the individual design sessions to define their own concept (i.e. the PDInd concept). The assessment was conducted on the afternoon. All drivers were different from those who attended the participatory workshop. Participants were selected based on their activity (city or regional delivery), age (between 18 and 66 years old) and gender (men) to be representative of the French population of delivery truck 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 and reported normal or corrected-to-normal vision.

2.2. Equipment

The assessment was led on the same driving simulator than 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^{TM} for traffic scenario and truck model. Concepts of instrument cluster were displayed on the 15.4 inches screen behind the steering wheel (height: 332mm, width: 207mm, resolution: 1920x1080). To capture driver’s eye gaze, a binocular head-mounted eye tracker was used (Tobii Glasses 2; scene camera resolution: 1920x1080; eye camera tracking frequency: 50Hz). Gaze raw data were filtered using the Tobii I-VT fixation filter configured so as short fixations were not discarded (Olsen, 2012).

2.3. Material

2.3.1. *Concepts*

The three concepts of instrument clusters were defined using the same equipment, instructions, and scope. Concept generation was made using specific touchscreen software installed on a driving simulator (Fig. 1). This allowed iterative driving to assess and contextualize concepts during design. While building the instrument cluster on the touchscreen, the content was instantaneously displayed to scale on a screen behind the steering wheel, and widgets were interactive and updated during driving (connected to the dynamic model of the driving simulator). Users could select information among 17 functions categories (e.g. speed) with a total of 186 different available widgets (e.g. analogue semi-circular speedometer, digital speedometer, linear vertical speedometer). A list of mandatory functions to display was made available to them: speed, gearbox information (mode and lever position), retarder, mode and target speed of the ADAS. They also could move and resize widgets on the stage. The following instruction was given to users for the design activities: to create the main page of a dashboard containing the information necessary for a delivery truck.

The method and equipment of the design sessions is explained in more details in Francois et al. (2017b).

The concept from the user-centered design process (UCD)

The UCD concept was designed first by two professional HMI experts from Renault Trucks (a man and a woman; respectively 40 and 42). They defined the concept considering various aspects and requirements such as cognitive ergonomics, human factors design guidelines, drivers' profiles, city and regional delivery activity, brand image, etc. In a first design session of four hours, three different concepts were proposed. After a usability test performed with nine internal truck drivers (working at Renault Trucks), redesign was made on one final concept considering drivers' feedback and suggestions (Fig. 2).

The concept from the participatory design workshop (PDWS)

The PDWS concept was defined during a participative workshop involving four professional truck drivers (all men, mean age: 36 years, SD: 12) and three HMI practitioners (two of them participated in UCD). During this workshop, different activities were led (i.e. narrate, prioritize, and create activities) in order to encourage drivers to define an instrument cluster. HMI practitioners had a role of facilitators and experts. After a pooling phase, the drivers validated a final concept (Fig. 2).

The concepts from individual participatory design sessions (PDInd)

The PDInd concepts were created the same morning by each driver participating in the assessment. The 27 truck drivers were different from those who attended the participatory workshop. During the design session, each driver was with a facilitator. After a narrative activity, he sat on the simulator to construct his concept and evaluate it iteratively in a driving situation. The driver decided when his concept was complete. Examples of PDInd concepts are presented in Fig. 3.

2.3.2. *Driving scenario and tasks*

The assessment contained three driving scenarios, each lasting about 20 minutes. Participants had to respect the arrows displayed on the road screen to drive in the requested direction. In each scenario, 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. At different locations of the scenario, task instructions were enunciated through the radio. 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). Task instructions were chosen to match with actions carried out frequently by delivery drivers during their activity.

2.4. Procedure

Participants spent half of the day designing their own concept before this experimental assessment phase. The assessment started after a long break (more than 30 minutes) to prevent driver's weariness. At the beginning of the assessment phase, the procedure and instructions were exposed. The eye tracker was set up and calibrated. The test was composed of three test drives (one per concept tested). The order in which the three concepts were presented was counterbalanced by following a Latin square. 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. Before each test drive, participants were given a 10 min trial, in order 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 enunciated through the radio. The driver could then give his answer aloud or complete the required action. The total test duration was approximately three hours.

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. 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, he could choose a widget that was displayed on the stage. He could then change his size and location.

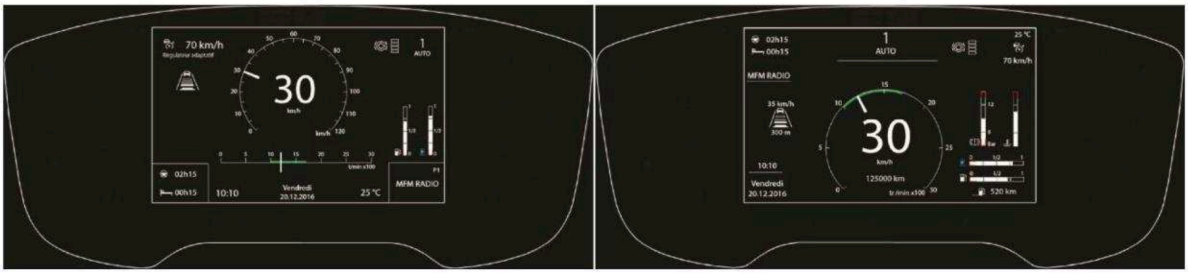

Figure 2. Concept resulting from the user-centered design process (UCD concept), and from the participatory workshop (PDWS concept).

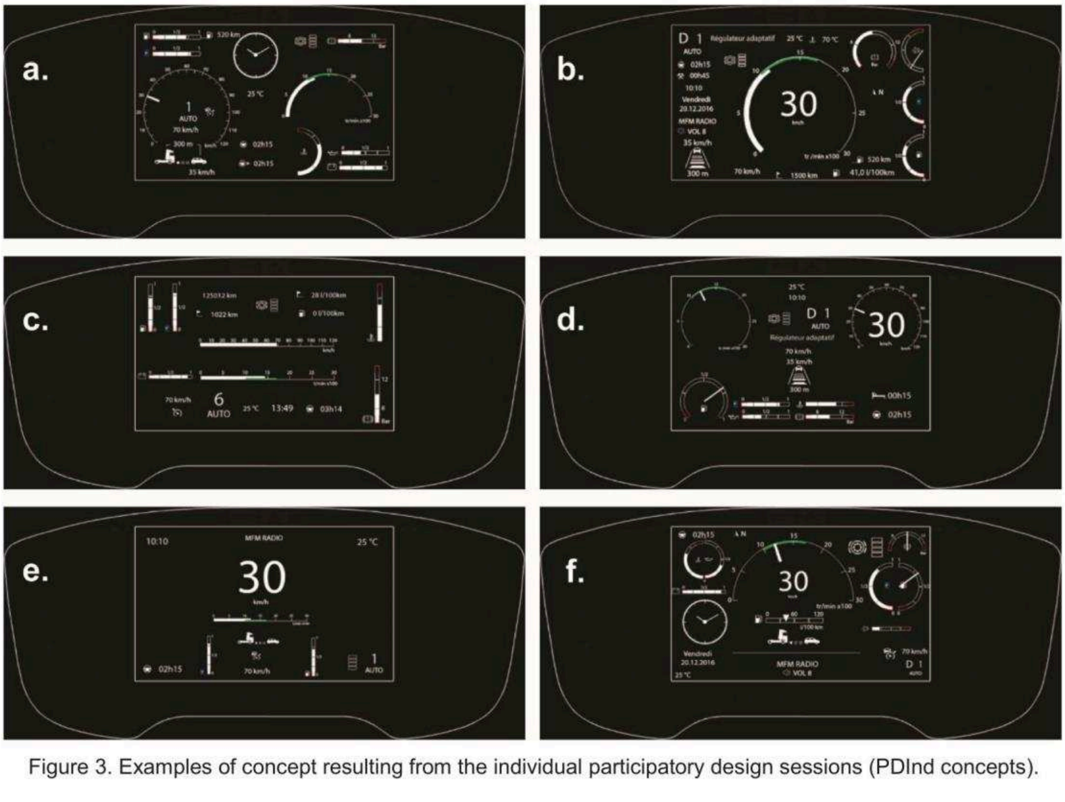

Figure 3. Examples of concept resulting from the individual participatory design sessions (PDInd concepts).

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

Task ID	Task instruction	Expected answer
Task 1	Which is the gear 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

3. Results

Due to the large number of variables, only the significant results are reported below. The complete results are presented in Table 2, Table 3, and Table 4.

3.1. Efficiency and visual distraction

3.1.1. Global results

For each participant and each task, a normalization procedure was used to generate z-scores for the task completion times and eyes-off-road times (Fig. 4). This allowed making global comparisons across tasks, without suffering from the different orders of magnitude of the eleven tasks. A two-way multivariate analyses of variance (MANOVA) was run with two independent variables (concept and task) and two dependent variables (task completion times and eyes-off-road times).

There was a statistically significant effect of the concept on the combined dependent variables, *F*(4, 23)= 4.606, *p*= .007, partial η^2= .445. Follow up MANOVAs showed a statistically significant difference between the UCD concept (*M*= -0.13 for the task completion times, and *M*= -0.20 for the eyes-off-road times) and the PDWS concept (respectively *M*= 0.13 and *M*= 0.13) on the combined dependent variables (*F*(2, 25)= 8.013, *p*= .0.002, partial η^2= .391). The differences between the UCD concept and the PDInd concepts resulted in a statistical trend (*M*= 0.00 and *M*= 0.05; *F*(2, 25)= 3.059, *p*= .064, partial η^2= .197).

3.1.2. Results per task

One-way multivariate analyses of variance were run for each task to determine the effect of the tested concept on the tasks completion times (Fig. 5) and the eyes-off-road times (Fig. 6).

For the task 2, the differences between the concepts on the combined dependent variables revealed a trend toward significance, *F*(4, 23)= 2.236, *p*= .087; partial η^2= .288. LSD post-hoc tests showed that for task completion times, the PDInd concept collected statistically significantly higher times (*M*=2565) than the UCD concept (*M*=2179; *p*= .010) or the PDWS concept (*M*=2247; *p*= .031). For eyes-off-road times, post-hoc tests showed that the PDInd concept also collected significantly higher times (*M*=1315) than the UCD concept (*M*=878; *p*= .002) or the PDWS concept (*M*=945; *p*= .007).

Concerning task 3, the MANOVA showed a significant difference between the concepts on the combined dependent variables, *F*(4, 23)= 8.600, *p*< .001; partial η^2= .599. LSD post-hoc tests showed that for task completion times, the PDWS concept collected statistically significantly higher times (*M*=4530) than the UCD concept (*M*=3801; *p*< .001) or the PDInd concept (*M*=3952; *p*< .001). Similarly, the PDWS concept also collected significantly higher eyes-off-road times

Table 2. Mean z-scores, task completion times, and eyes-off-road times (with the associated standard deviations) and the results of the statistical tests. The grey cells represent the significant measures: †= trend (.1<*p*<.05), * = *p*<.05, ** = *p*<.01

Z-scores of task completion and eyes-off-road times

		Task completion times	**Eyes-off-road times**	**MANOVA $F_{(4,23)}(p)$**	**MANOVAs $F_{(2,25)}(p)$**		
		M (SD); N= 27		**Concept**	**UCD-PDWS**	**UCD-PDInd**	**PDWS-PDInd**
All tasks	**UCD**	-0,13 (0.39)	-0,20 (0.38)	4.606 (.007) **	8.013 (.002) **	3.059 (.065) †	0.598(.557)
	PDWS	0,13 (0.42)	0,15 (0.41)				
	PDInd	0,00 (0.41)	0,05 (0.41)				

Task completion and eyes-off-road times per task

		Task completion times	Eyes-off-road times	MANOVA $F_{(4,23)}(p)$	LSD Post hoc tests $p_{task\ completion\ times},\ p_{eyes\text{-}off\text{-}road\ times}$					
		M (SD); N= 27		Concept	UCD-PDWS		UCD-PDInd		PDWS-PDInd	
Task 1	UCD	3236 (528)	1412 (652)	0.455 (.767)						
	PDWS	3147 (430)	1293 (508)							
	PDInd	3116 (471)	1259 (425)							
Task 2	UCD	2179 (306)	878 (323)	2.326 (.087) †	.638	.613	.010 *	.002 **	.031 *	.007 **
	PDWS	2247 (431)	945 (386)							
	PDInd	2565 (828)	1315 (807)							
Task 3	UCD	3801 (501)	1749 (425)	8.600 (.000) **	.000 **	.000 **	.353	.784	.001 **	000 **
	PDWS	4530 (991)	2417 (743)							
	PDInd	3952 (678)	1785 (521)							
Task 4	UCD	10303 (3402)	4753 (2189)	0.759 (.562)						
	PDWS	10816 (3525)	4782 (2568)							
	PDInd	11125 (3553)	4918 (2425)							
Task 5	UCD	4940 (295)	1394 (605)	2.663 (.058) †	.193	.282	.676	.022 *	.373	.207
	PDWS	5075 (343)	1553 (665)							
	PDInd	4983 (558)	1740 (610)							
Task 6	UCD	12522 (3862)	5385 (2191)	1.218 (.330)						
	PDWS	13525 (5550)	6167 (2695)							
	PDInd	14944 (5097)	6895 (4007)							
Task 7	UCD	10200 (5233)	4368 (2853)	5.629 (.003) **	.001 **	.000 **	.051 †	.095 †	.159	.012 *
	PDWS	15069 (7560)	7894 (4963)							
	PDInd	13040 (6651)	5765 (3762)							
Task 8	UCD	3127 (738)	1486 (598)	0.372 (.826)						
	PDWS	3156 (714)	1442 (614)							
	PDInd	3201 (946)	1427 (536)							
Task 9	UCD	3127 (869)	1522 (485)	0.869 (.497)						
	PDWS	3384 (1331)	1606 (719)							
	PDInd	3390 (1860)	1828 (1170)							
Task 10	UCD	2862 (957)	1650 (614)	1.195 (.340)						
	PDWS	3153 (1132)	1959 (782)							
	PDInd	2927 (1970)	1702 (1321)							
Task 11	UCD	3736 (817)	1573 (476)	0.896 (.482)						
	PDWS	4090 (1308)	1891 (762)							
	PDInd	3987 (1481)	1800 (1002)							

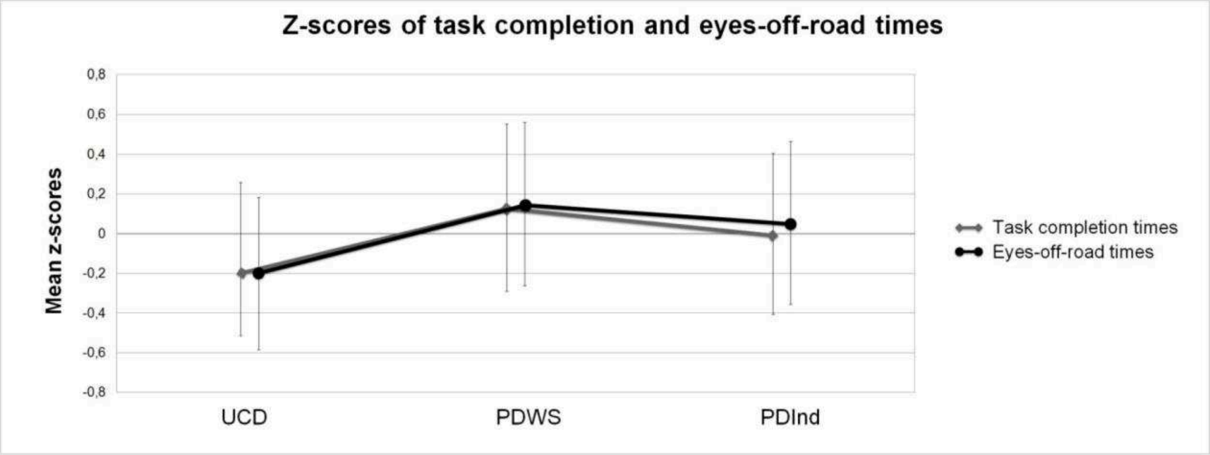

Fig 4: Mean z-scores off tasks completion times and eyes-off-road times results for the three concepts for all tasks.

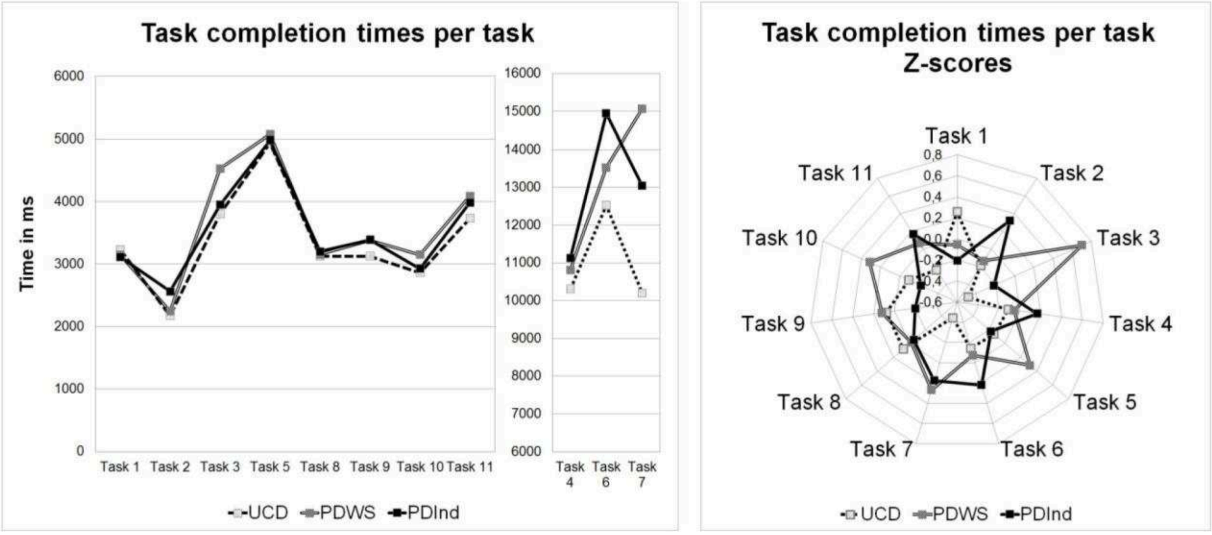

Fig 5: Task completion times per task for each concept: average times (in ms) and z-scores.

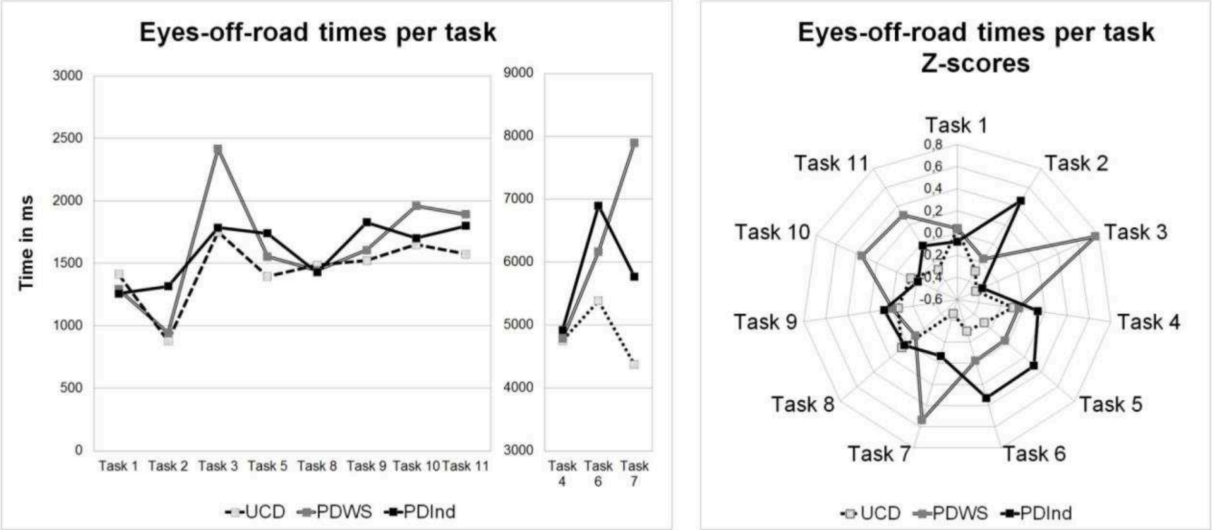

Fig 6: Eyes-off-road times per task for each concept: average times (in ms) and z-scores.

(*M*=2417) than the UCD concept (*M*=1749; *p*< .001) or the PDInd concept (*M*=1785; *p*< .001).

For the task 5, the effect of the concept on the combined dependent variables revealed a statistical trend, *F*(4, 23)= 2.663, *p*= .058; partial η^2= .317. Eyes-off-road times were significantly lower with the UCD concept than with the PDInd concept (*p*= .022).

Finally, for the task 7, the MANOVA on the combined dependent variables showed a significant effect of the concept (*F*(4, 23)= 5.629, *p*= .003; partial η^2= .495). Task completion times were significantly lower with the UCD concept (*M*= 10200) than with the PDWS concept (*M*=15069; *p*< .001) and the difference with the PDInd concept was tending toward significance (*M*=13040; *p*= .051). Eyes-off-road times were significantly higher for the PDWS concept (*M*=7894) than for the UCD concept (*M*=4368; *p*< .001) and the PDInd concept (*M*=5765; *p*= .012), but the difference between the UCD concept and the PDInd concept revealed a statistical trend (*p*= .095).

3.2. Accuracy

Friedman tests were run for each task to determine if there were differences in accuracy between the three concepts (Fig. 7). For the task 1, the task 3, the task 8, and the task 11, accuracy scores were a mean of the number of errors when giving the answer. For the task 2, the task 9, and the task 10, accuracy scores were the average distance to the real value at the beginning of driver's answer. Finally, for the task 4, the task 6, and the task 7, accuracy scores were the number of failures to perform the requested action.

For all tasks except task 7, differences between the UCD, the PDWS and the PDInd concepts were not significant (Table 3). Regarding the task 7, the Friedman test revealed a statistical trend ($\chi^2(2)$=

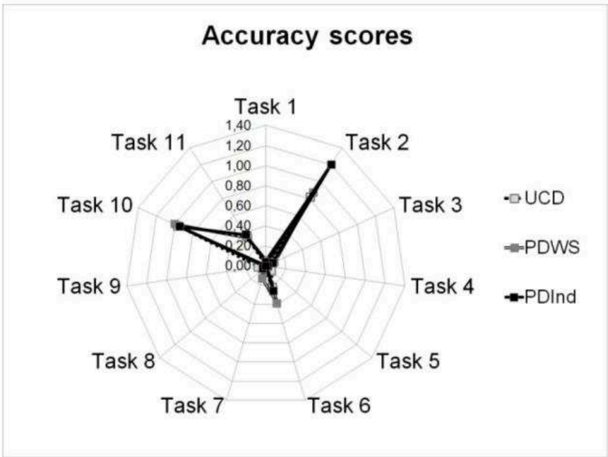

Fig 7: Accuracy scores per task for the three concepts.

Table 3. Mean accuracy scores (with the associated standard deviations) and the results of the statistical tests (†= trend, .1<p<.05)

Accuracy

	Accuracy scores M (SD); N= 27			Friedman test $\chi^2_{(2)}$ (*p*)
	UCD	**PDWS**	**PDInd**	**Concept**
Task 1	0.00 (0.00)	0.06 (0.16)	0.04 (0.13)	2.800 (.247)
Task 2	0.81 (0.83)	0.87 (0.72)	1.20 (1.16)	2.141 (.034)
Task 3	0.02 (0.10)	0.09 (0.20)	0.07 (0.23)	3.000 (.223)
Task 4	0.00 (0.00)	0.00 (0.00)	0.02 (0.10)	2.000 (.368)
Task 5	0.07 (0.23)	0.02 (0.10)	0.00 (0.00)	3.500 (.174)
Task 6	0.22 (0.38)	0.39 (0.42)	0.26 (0.42)	1.962 (.375)
Task 7	0.04 (0.19)	0.13 (0.33)	0.00 (0.00)	5.200 (.074) †
Task 8	0.04 (0.13)	0.02 (0.10)	0.04 (0.13)	1.000 (.607)
Task 9	0.07 (0.30)	0.02 (0.10)	0.00 (0.00)	2.000 (.368)
Task 10	0.96 (0.46)	1.00 (0.57)	0.94 (0.53)	0.220 (.896)
Task 11	0.35 (0.48)	0.33 (0.39)	0.37 (0.47)	0.000 (1.000)

	Wilcoxon pairwise comparisons; *Z* (*p*)		
Task 7	**UCD-PDWS**	**UCD-PDInd**	**PDWS-PDInd**
	1.079 (.281)		1.826 (.068) †

5.200, *p*= .074). The Wilcoxon test for paired samples showed that the difference in accuracy between the PDWS (*M*= 0.13) and the PDInd concepts (*M*= 0.00) was tending toward significance (*p*= .068).

3.3. Driving performances

One-way multivariate analyses of variance were conducted to determine whether there was a statistically significant difference between concepts on longitudinal control measures and lateral measures whatever the task performed (Fig. 8).

None of the driving performance measures resulted in significant differences between the three concepts (Table 4).

4. Discussion

4.1. Findings

4.1.1. RQ1: Does the level of driver involvement influence efficiency and distraction of instrument clusters?

The results showed that concept generated with the UCD process implied globally lower task completion and eyes-off-road times than the concept of the participatory workshop. For the task 3 (i.e. read the fuel gauge), task completion was 729ms faster with the UCD concept than with the PDWS concept (19%), with a reduction of visual distraction of 668ms (38%). Similarly, the task 7 (i.e. set the speed limiter) was completed faster with the UCD concept (gain of 4 870ms/48%) with a significant reduction of eyes-off-road time (gain of 3 526ms/81%). The UCD concept also collected better results than the individual concepts (PDInd). All tasks combined, task completion and eyes-off-road times tended to be lower. The task 2 (i.e.

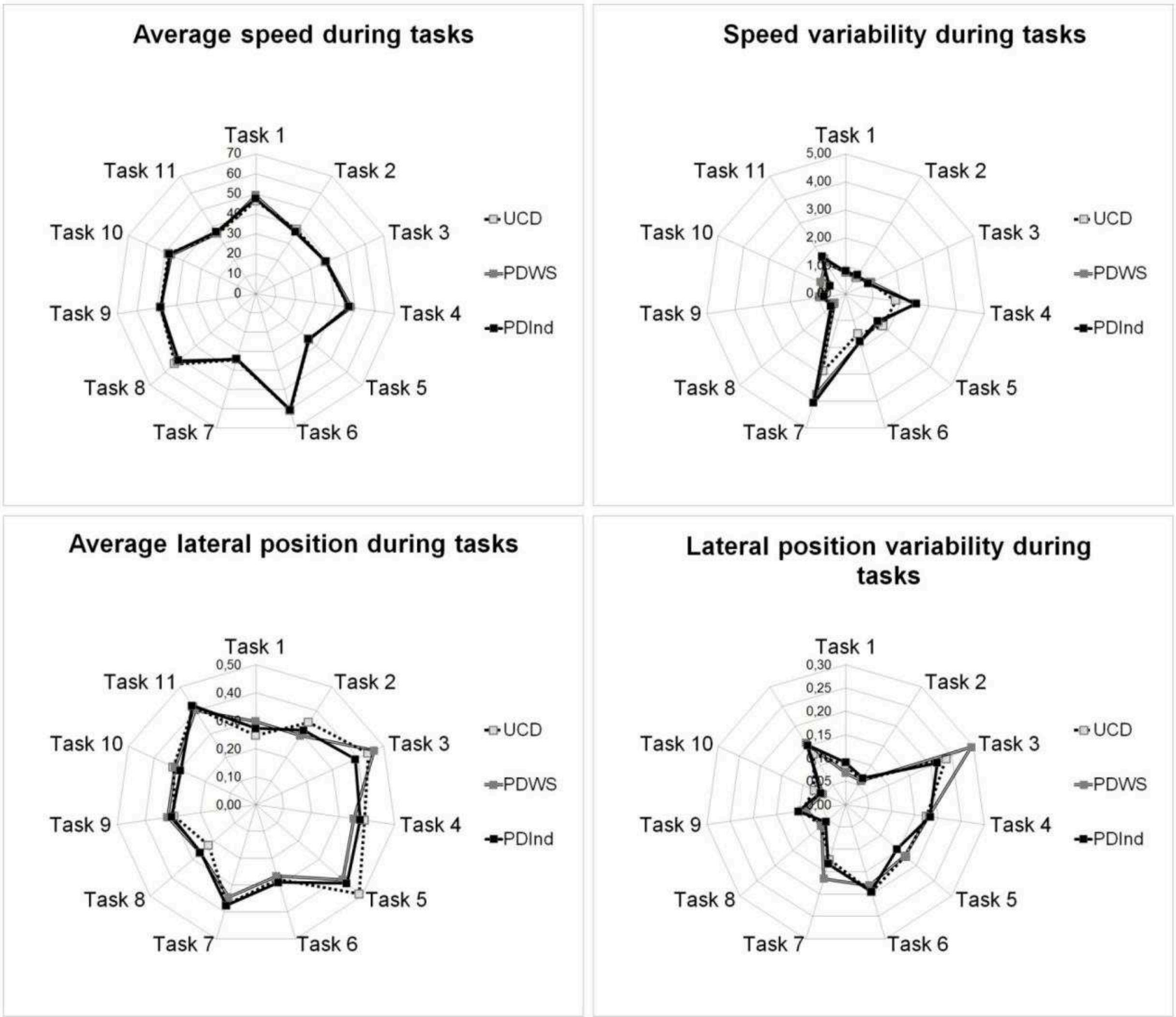

Fig 8: Speed (average and standard deviation) and lateral position (average and standard deviation) during tasks completion for the three concepts.

Table 4. Means of the average speed, speed variability, average lateral position, and lateral position variability (with the associated standard deviations) and the results of the statistical tests.

Driving performances

		Average speed		Speed variability		Average lateral position		Lateral position variability	
		M (SD); N= 27	**MANOVA $F_{(22,5)}(p)$**	**M (SD); N= 27**	**MANOVA $F_{(22,5)}(p)$**	**M (SD); N= 27**	**MANOVA $F_{(22,5)}(p)$**	**M (SD); N= 27**	**MANOVA $F_{(22,5)}(p)$**
All tasks	**UCD**	44.14 (12.10)	2.303 (.180)	1.28 (1.19)	0.927 (.601)	0.35 (0.19)	1.110 (.502)	0.13 (0.10)	1.133 (.491)
	PDWS	44.05 (12.19)		1.44 (1.74)		0.34 (0.18)		0.13 (0.13)	
	PDInd	43.87 (12.25)		1.46 (1.72)		0.34 (0.18)		0.13 (0.11)	

read the speed) was completed faster with less visual distraction with the UCD than with the PDInd concept (gain of 387ms/18% in task completion; and 438ms/50% in eyes-off-road times). For the task 5 (i.e. speed relative reading), the UCD concept also implied a lower visual distraction (gain of 345ms/25%). Finally, to set the speed limiter, efficiency and visual distraction tended to be better with the UCD than with the individual concepts (difference of 2 841ms/28% in task completion; and 1 396ms/32% in eyes-off-road times). On the other side, no significant difference was found between the outcomes of the two levels of user involvement in terms of accuracy and driving performance.

Regarding results, we can conclude that efficiency and distraction were better with the instrument cluster resulting from the user-centered design process than with the two participatory design instrument clusters. Even if the differences were observed significantly only on four tasks, the overall standardized analysis emphasized a global trend between the three concepts tested. Although differences were smalls for some tasks, they were constant in term of order: the UCD concept tended to be more efficient and less distracting than the PDInd concept, and was significantly better than the PDWS concept. Moreover, for some tasks, the mean gain in visual distraction with the UCD concept amounted to more than three seconds (compared to the PDWS on the task 7) which could be critical for road safety. These findings demonstrated that professional designers can rely on their knowledge and expertise to design effective dashboards and minimize distraction. On the contrary, drivers would not have a good meta-representation of what they could use efficiently and safely. This is in line with the results of DeSmet et al. (2016) showing that PD can be counterproductive in effectiveness for medical serious games. The 'pragmatic' benefit of PD (Carroll & Rosson, 2007) is questioned for the design of products for which objective criteria such as efficiency are crucial. The trend for more and more user involvement in design (Marcus, 2004; Sanders & Stappers, 2008) is challenged and should be investigated further.

4.1.2. *RQ2: Is there an efficiency and distraction gap between what a driver has defined for him, and what other drivers have defined for him?*

Differences between the two concepts resulting from two different participatory methods have been demonstrated. The concepts from the individual participatory design sessions were significantly better than the concept from the participatory workshop to read the fuel gauge (task 3; gain of task completion times: 579ms/15%; gain of eyes-off-road times: 631ms/35%). When drivers were asked to set speed limiter (task 7), the reduction in visual distraction was even more marked (2 129ms/35%) and the task tended to be completed with less errors with individual concepts than with the PDWS concept. On the contrary, for the task 2 (i.e. read the speed), task completion times and eyes-off-road times were lower with the PDWS concept than with the PDInd concepts (gain of task completion times: 319ms/14%; gain of eyes-off-road times: 370ms/39%). However, these gaps of efficiency and distraction seemed to be isolated on these three tasks, as there were no significant differences in terms of global normalized results. These findings showed that significant differences exist between the efficiency and distraction of instrument clusters developed with PD, suggesting that certain methods of PD could be more effective. This idea matches the results reported by DeSmet et al. (2016), which highlighted differences in effectiveness of medical serious games according to the participative method implemented. Nevertheless, we cannot conclude in favor of one or the other method, because differences were isolated on certain tasks and go in either direction depending on the task performed. Besides that, the absence of negative impact on driving performance for both participatory concepts corroborates and objectifies the feeling reported by the drivers in the study of Normark and Gustafsson (2014) that driving with a customized cockpit did not affect driving.

4.2. Limitations and perspectives

The findings of this study should be considered in light of some limitations. First, the results cannot be extended to UCD or PD in general. There are many other ways to collect a UCD outcome (e.g. with others or more designers, other levels of designer expertise, more iterations, more drivers to test concepts) or to achieve a PD result on the same design case (e.g. different roles for users and designers, other design activities, a higher number of drivers involved). The results could vary depending on these factors, so it would be interesting to continue the evaluations in a methodical way on the outcomes of the different approaches.

Second, this study attempts to compare the three concepts rigorously on the same basis. However, it would be interesting to investigate whether these results vary over time, all the more in a perspective of personalization. Additionally, the three resulting concepts were compared in order to indirectly evaluate the design method, but it would be interesting to identify and specify the parameters that vary between the different concepts, such as the display clutter that can affect visual-search efficiency (Moacdieh & Sarter, 2015) or the efficiency of the chosen representations for each function.

Third, the results of this article call into question the benefits of PD in terms of objective measures. However, it is important to stress that it does not reduce the weight of other benefits such as new knowledge, skills, collaborations (Bratteteig & Wagner, 2016), ot the consideration of inter-individual differences (Lo, Pluyter, & Meijer, 2016) and cultural aspects (Kisaalita, Katimbo, Sempiira, & Mugisa, 2016).

Finally, the non-correspondence between these objective results and the subjective benefits reported in Francois et al. (2017b) is a key point. This mainly questions the links between perceived usability and current usability and between use and acceptance. Complementary data would be useful to clarify these issues (e.g. analysis of the temporal dynamic).

Key points

- The instrument cluster generated with the user-centered design process was more efficient and less distracting than the participatory workshop concept.
- Although the difference was smaller, the user-centered design concept was found better in efficiency and distraction than individual participatory concepts.
- The two participatory concepts differed on certain tasks, with deviations going in one direction or the other depending on the task performed.
- No difference was found between the three concepts in terms of accuracy and driving performance.

References

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).

Bachore, Z., & Zhou, L. (2009). A critical review of the role of user participation in IS success. *AMCIS 2009 Proceedings*, 659.

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.

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.

Bossen, C., Dindler, C., & Iversen, O. S. (2016, August). Evaluation in participatory design: a literature survey. In *Proceedings of the 14th Participatory Design Conference: Full papers-Volume 1* (pp. 151-160). ACM.

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.

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.

DeSmet, A., Thompson, D., Baranowski, T., Palmeira, A., Verloigne, M., & De Bourdeaudhuij, I. (2016). Is participatory design associated with the effectiveness of serious digital games for healthy lifestyle promotion? A meta-analysis. *Journal of medical Internet research*, *18*(4).

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., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2017a). Automotive HMI design and participatory user involvement: review and perspectives. *Ergonomics*, *60*(4), 541-552.

François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2017b). *Usability and acceptance of truck dashboards designed by drivers: two participatory design approaches compared to user-centered design.* Manuscript submitted for publication.

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.

International Organization for Standardization (2010). *ISO 9241-210 - Ergonomics of human-system interaction – Human-centered design for interactive systems*. International Organization for Standardization.

Kisaalita, W. S., Katimbo, A., Sempiira, E. J., & Mugisa, D. J. (2016). Cultural Influences in Women-Friendly Labor-Saving Hand Tool Designs: The Milk Churner Case. *Human factors*, *58*(1), 27-42.

Kujala, S. (2003). User involvement: a review of the benefits and challenges. *Behaviour & information technology*, *22*(1), 1-16.

Lo, J. C., Pluyter, K. R., & Meijer, S. A. (2016). Individual Markers of Resilience in Train Traffic Control: The Role of Operators' Goals and Strategic Mental Models and Implications for Variation, Expertise, and Performance. *Human factors*, *58*(1), 80-91.

Marcus, A. (2004). The next revolution: vehicle user interfaces. *Interactions, 11*(1), 40-47.

Moacdieh, N., & Sarter, N. (2015). Display clutter: A review of definitions and measurement techniques. *Human factors*, *57*(1), 61-100.

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.

Olsen, A. (2012). The tobii i-vt fixation filter. Tobii Technology. Retrieved from https://stemedhub.org/resources/2173/download/Tobii_WhitePaper_TobiiIVTFixationFilter.pdf

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.

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.

Strayer, D. L., Turrill, J., Cooper, J. M., Coleman, J. R., Medeiros-Ward, N., & Biondi, F. (2015). Assessing cognitive distraction in the automobile. *Human factors*, *57*(8), 1300-1324.

Tractinsky, N., Katz, A. S., & Ikar, D. (2000). What is beautiful is usable. *Interacting with computers*, *13*(2), 127-145.

Volvo Group Trucks Technology (2015). *Identify and specify MPV HMI Context of use*. Internal report: unpublished.

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Discussion

This thesis aimed at improving knowledge on the more efficient way to involve drivers to create easy to use and safe truck interfaces. The effects of the level of driver involvement in trucks HMI design process was investigated in terms of usability, distraction and acceptance. Moreover, two participatory methods were compared: a collective participatory workshop and individual design sessions. After a preliminary literature review of the benefits of participatory design in other fields, the first sub-project aimed at identifying and specifying the context of use of multi-purpose vehicles HMI. Then, the second sub-project consisted in conducting three design processes of instrument cluster using the same tactile equipment. Finally, the third sub-project aimed at assessing the outcomes from the three processes generated in the second sub-project. Usability, distraction and acceptance were measured with predefined scenarios and tasks involving the use of the interfaces.

In this part, the main findings of each sub-project are summarized and discussed. Then the limitations of this research are exposed (on the object of study and on the design processes) as well as the research perspectives. Finally, recommendations to practitioners are proposed.

1. Findings

1.1. State of the art

At the beginning of this project, a state of the art was conducted to review the benefits of participatory design and to link them to the current challenges of HMI design. This review offered a global vision of HMI design in a holistic and practical framework. The conventional approach of automotive HMI design was presented, and light was shed on issues of user-centered design. Participatory design was proposed as a potential alternative, already employed in other fields of human-factors research. An important argument for the employment of participatory design seems to be that this approach may allow to access drivers’ tacit knowledge. Such knowledge about the drivers may improve the usability and safety of HMI. Furthermore, the consideration of drivers' tacit needs and preferences may also improve the acceptance of HMI. Besides that, a lack of formal evaluation was reported, with the necessity to conduct a relative comparison between the different levels of user involvement to gauge the gap in terms of outcomes ergonomic quality. The potential limitations of participatory design were also highlighted to ensure a global view (i.e. a lack of formalized methodology, a low validity of processes evaluation, and the doubts on users' ability to add value in the concept design phase). Reviewing literature on participative design and shedding light on a potential alternative to face HMI contemporary challenges could be helpful for researchers and practitioners.

1.2. Sub-project 1: Analysis of the context of use

In human-centered design processes, the knowledge of the context of use (i.e. characteristics of the users, tasks and environment in which systems are used) is an essential input. In this project, the goal was to design and evaluate concepts from different human-centered approaches. Therefore, a prior analysis of the context of use was conducted through two studies.

The first study was an analysis of multi-purpose trucks in terms of usages, activities, and environment of use. Quantitative data from a database of more than 5 000 trucks were collected and analyzed. Results showed that MPV usages and applications are diverse. A multiple correspondence and a cluster analysis divided vehicles into four groups. The first group, representing 60% of multi-purpose vehicles, was chosen as target for our design activities. In this group, vehicles were mainly van and conditioned body for local and regional deliveries. In this sense, the context of assessment of the third sub-project consisted in country and city roads. Additionally, the drivers involved in participatory design sessions were local or regional professional delivery drivers. The data also demonstrated that the configurations of controls on the dashboard were various between trucks. The instrument cluster, common to all vehicles, was thus chosen as object of study for the design activities. The HMI configuration of these trucks was mainly basic and driving oriented HMI. The scope of the design activities consequently concentrated on basic driving functions. Nevertheless, the main limitation of this study was that the reported data indicated the presence or absence of a function in vehicles. However, the presence of functions in vehicles does not provide any information on their frequency of use, although this measure is determinant for HMI conception. An activity analysis could complement this study by measuring frequency of use for each HMI part.

The second study presented the results of a survey aiming at improving MPV driver knowledge. Sixty-eight MPV drivers answered a questionnaire on their profile, their job, their actual HMI, and their expectations for a future HMI. Results showed that few MPV drivers were beginners (we can therefore except they know well HMI functions) and that they were mainly comfortable with technology (and smartphones). Based on this, the choice of a tactile prototyping tool was comforted. Questions aiming at prioritizing their HMI needs and expectations highlighted 5 “must-have”: “Cruise control”, “Driving times information in the instrument cluster”, “Trip and fuel consumption information in the instrument cluster”, “Integrated GPS” and “Reverse camera”. These data were used by experts in the user-centered design process. Indeed, cruise control and driving times information were prioritized in the UCD concept. The survey results showed that MPV drivers were mostly men between 18 and 66 years old. This information was used for the selection of drivers participating in participatory activities, to ensure the representativeness of end-users. This survey was innovative in the way to access drivers (i.e. Facebook and training center). However, one limitation is the size of the sample (68 respondents). This small size did not enable to perform multiple correspondence and clustering analyses on MPV drivers (quantitative “personas”; Maguire, 2001).

On the whole, findings from the sub-project 1 allowed to have a better representation of users and usages. Moreover, the quantitative techniques used for the analysis of the context of use provided a synthetic overview that could be transferrable to other fields.

1.3. Sub-project 2: Concepts design

1.3.1. User-centered design

The user-centered design was one of the three design processes conducted in parallel in this study, and whose resulting concept was evaluated in the third sub-project. This concept corresponded to a consultative level of involvement (i.e. drivers evaluate concepts designed by experts). Consequently, experts needed inputs to define concepts. The data from the first sub-project were used, and a work was carried out on human-factors guidelines.

Indeed, a review of existing human-factors guidelines was first conducted. This document gathered existing technical literature, in which guidelines or recommendations were presented to promote usability while designing in-vehicle HMI. The overall view offered by this document could be used in automotive industry.

Besides that, some experiments were leaded to complement these guidelines. First, two experiments investigated the more efficient and satisfying way to display the speedometer on a screen instrument cluster. A first study comparing a digital speedometer and an analogue speedometer replicated previous results of the literature (i.e. the better speedometer depends on the task performed). Based on it, a second study assessed and compared both conventional speedometers and a redundant speedometer on contemporary use cases. Second, an experiment on gauges’ design compared eight gauges mixing different attributes (i.e. shapes, orientation, and indicators). Results showed that eyes off-road time can be decreased by 280ms by changing the design of a gauge, or by more than 600ms when using a redundant instead of an analogue speedometer. These findings underlined the need to conduct human-factors studies to design more efficient and safe interfaces.

These data were used by experts while defining the user-centered design concept. For example, the speedometer chosen in the UCD concept was a redundant one. However, it is interesting to note that experts had to choose between ergonomic principles were competing. Indeed, in one hand, linear-vertical-bargraph gauges were found less efficient, more visually distracting, and less satisfying for qualitative reading than a linear-horizontal-pointer gauge. In the other hand, guidelines recommend that representation chosen should support drivers' mental model of reality (Ross et al. ,1996). Therefore, linear-vertical-bargraph gauges were chosen by experts for fuel and diesel exhaust fluid, as tanks that would be filled. Experts first generated three concepts, and invited nine internal drivers to assess them. Afterwards, experts redesigned a final concept. However, weaknesses of the process (i.e. few drivers involved during the assessment and no iteration) can be underlined.

1.3.2. Participatory design

Two participatory design processes were conducted, differing in the number of drivers involved during the design session. First, a collective workshop was carried out with four professional drivers. Second, individual design sessions were leaded. The resulting concepts were compared to the user-centered design concept in the third sub-project.

Regarding the implementation of participatory design for trucks HMI design, one of the limitations reported for participatory design was the broad range of practices used, without formalized methodology (Haines, Wilson, Vink, & Koningsveld, 2002; Pilemalm & Timpka, 2008; Spinuzzi, 2005). To overcome this limitation, Spinuzzi (2005) proposed a PD methodology composed of three stages: initial exploration of the work, discovery process, and prototyping. In this research, the three stages were applied: the first sub-project of analysis corresponded to stage 1, the narrative activities corresponded to stage 2, and the design sessions around the prototyping tool corresponded to stage 3. Moreover, a particular interest was given to the prototyping tool, essential to let users express themselves (Sanders, 2002). The touchscreen seemed to be an appropriate visual and projective tool to facilitate exchange (already used by Normark, 2015). Additionally, the combined use with the driving simulator allowed users to iterate between design and assessment. Bruno and Muzzupappa (2010) reported that, in many participatory studies, the physical mock-up of the concept often appears late. In this study, the "making activities" and the "enacting activities" (Sanders et al., 2010) were mixed to contextualize designs. This brought validity to the concepts created by drivers, who did not content to stack ideas or draw unrealizable patterns as it can be the case in participatory paper-pencil workshops.

Another potential limitation often reported for participatory design is the gap between participation and involvement. Indeed, Barki and Hartwick (1994) pointed out that user participation is not always a gage of involvement. They clarified the two notions as follows: participation would refer to “a set of behaviors or activities performed by users in the system development process”, while involvement would be defined as “a subjective psychological state reflecting the importance and personal relevance of a system to the user”. In this study, measures of user involvement were performed (scale used in the study of Hunton and Beeler, 1997; based on the original questionnaire of Barki and Hartwick, 1994). For the two participatory methods, the scores of users’ involvement – based on items on importance and personal relevance – were high (values close to 6 on a scale of 7 for both concepts). Similarly, user attitude (> to 5.67), perceived self-efficacy (> to 5.93), and desired participation (> to 6.56) collected high scores. In both methods, drivers gave a positive feedback on their participation, and reported a high level of involvement.

1.4. Sub-project 3: Concepts assessment

The aim of this sub-project was to evaluate and compare the three concepts of instrument cluster in terms of usability, distraction and acceptance. Twenty-seven drivers assessed the UCD concept, the PDWS concept, and their own concept. Usability, distraction and acceptance were measured on truck simulator with predefined scenarios and eleven tasks involving the use of the interfaces. Previous studies already compared human-centered approaches. For instance, Carmel et al. (1993) compared joint application design and participatory design. Carroll (1996) compared PD and UCD, and Bekker and Long (2000) compared UCD, PD, socio-technical design, soft systems methodology, and joint application design. However, these comparisons were more theoretical, aiming at defining approaches boundaries and specificities. Bratteteig and Wagner (2006) stressed an urge to move the attention from how to carry an approach to how successful outcomes are. Here, the two human-centered approaches were systematically compared on the same design case and with the same equipment. What differentiated the outcomes from the three processes were the people who defined them. Moreover, the assessment was carried out rigorously in accordance with the experimental method.

1.4.1. RQ1: How the level of driver involvement in the design process impacts the usability, distraction and acceptance of truck HMI?

Regarding the impact of user involvement on usability, distraction and acceptance, two impact patterns were revealed (Table 1).

Table 1: Summary of the results for each variable for the differences between the user-centered design (UCD) and the participatory design workshop (PDWS) concept, and between the UCD and the individual participatory design (PDInd) concepts, ns = non-significant, †= trend (.1<p<.05), * = p<.05, ** = p<.01

			UCD vs PDWS	UCD vs PDInd
Usability	Perceived mental effort (RSME)		UCD better **	ns
	Global usability (SUS)		UCD better *	ns
	Usability dimensions (Home-made questionnaire based on Nielsen criteria)	Learnability	UCD better *	ns
		Efficiency	UCD better **	ns
		Memorability	UCD better **	ns
		Errors	UCD better **	ns
		Satisfaction	UCD better †	ns
Acceptance	Acceptance (Van der Laan)	Utility	ns	ns
		Satisfaction	UCD better *	ns
	Global satisfaction	Order of preference	ns	ns
		Satisfaction score	ns	ns
Efficiency and visual distraction	Global (z-scores; all tasks; combined variables)		UCD better **	UCD better †
	Per task		Task 3: UCD more efficient ** and less distracting ** Task 7: UCD more efficient ** and less distracting **	Task 2: UCD more efficient * and less distracting ** Task 5: UCD less distracting * Task 7: UCD more efficient † and less distracting †
Accuracy	Accuracy scores		ns	ns
Driving performances	Average speed		ns	ns
	Speed variability		ns	ns
	Average lateral position		ns	ns
	Lateral position variability		ns	ns

First, on subjective aspects (acceptance and perceived usability), it seems that 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 UCD concept was perceived as more usable and accepted than the PDWS concept, but was not significantly different from the PDInd concept (high scores of usability and acceptance for both).

Second, on objective measures (efficiency and visual distraction), the UCD concept was globally better than the two PD concepts. The UCD concept implied lower task completion and eyes-off-road times than the concept of the participatory workshop. This effect was global on all tasks on the combined variables (efficiency and visual distraction). The difference between both concepts resulted to be significant for two tasks, with differences up to 4 870ms/48% in task completion times and 3 526ms/81% in visual distraction reduction (task 7: set the speed limiter). Similarly, although the difference is reduced, the UCD concept also collected better results than the individual concepts. All tasks combined, task completion and eyes-off-road times tended to be lower. On three tasks, the UCD concept was measured as better than the PDInd concept (task 2: read the speed value; task 5: compare the speed to 30 km/h; and task 7: set the speed limiter). However, the amplitude of the gains was lower (gain of 387ms/18% in task completion and 438ms/50% in eyes-off-road times for task 2, and a statistical trend for task 7). On the other side, no significant difference was found between the outcomes of the two levels of user involvement in terms of accuracy and driving performance.

Based on the literature, the hypothesis was that the “pragmatic” benefit of participatory design (Carroll & Rosson, 2007) compared to user-centered design would rely on the access to users’ implicit needs and knowledge (Sanders, 2002). Access to implicit needs would have led to more useful interfaces, which would have increased their acceptance. Nevertheless, the UCD concept collected better acceptance scores than the PDWS concept, and scores were as good as those of individual concepts. The lack of significant difference for the utility dimension of the acceptance test is also interesting. Indeed, this would mean that the UCD concept addressed well users’ needs and expectations. Another interpretation could be that the design of the study could not have allow access to these needs. Indeed, the degree of freedom in design was limited to functions, size and presentation of information.

Moreover, drivers preferred an instrument cluster created for them by experts than an instrument cluster created for them by drivers. Experts, based on the explicit activities of analysis, would have a good knowledge of what users need and want. Likewise, there were few differences in terms of functions included in the instrument cluster between the UCD concept and participatory concepts (more than 80% of common functions).

Access to users’ tacit knowledge should have led to more usable and less distracting interfaces. However, the UCD concept was perceived as more usable than the PDWS concept, and the actual usability and visual distraction measures were also significantly better than with the PDWS concept. The application of human-factors guidelines, and a design centered on usability aspects, would therefore be more effective to create usable, efficient, and non-distracting interfaces than a participatory workshop. Regarding individual concepts, they were perceived to be as usable as the UCD concept. Nevertheless, the actual usability was higher, and visual distraction lower, with the UCD concept than with the PDInd concepts. There are two interpretations of this discrepancy between subjective and objective aspects. First, actual and perceived usability could be totally independent. Individual participatory sessions would result in good perceived usability, without positive impact on objective measures. In this sense, Tractinsky, Katz, and Ikar (2000) proposed that actual and perceived usability can be treated separately as they would evolve independently. Second, drivers could over-estimate their production. Indeed, 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 all cases, individual design sessions showed subjective benefits. Although differences were not significant, after testing the three concepts, more than half of drivers chose their concept first (52%), against 33% for the UCD, and 15% for the PDWS concept. On objective measures and under the conditions of this study, the fact that UCD showed better results could indicate that drivers had poor meta-representations of what they could process well. On the contrary, professional designers can rely on their knowledge and expertise to design effective dashboards and minimize distraction. This is in line with the results of DeSmet et al. (2016) showing that PD can be counterproductive in effectiveness for medical serious games. To conclude, experts would know better how to design safe and efficient instrument clusters than drivers, and they can define concepts as usable and accepted than drivers (or even more usable and accepted).

The main contribution on this research question is that “UCD is not dead”. The race towards ever more user involvement (Marcus, 2004; Sanders & Stappers, 2008), and the questioning of the ability of user-centered design to face contemporary challenges (Sanders & Stappers, 2008) have been called into question. Indeed, the UCD concept was assessed as usable, safe, and accepted. It is therefore essential to pursue research on human-factors guidelines.

1.4.2. RQ2: Is the ergonomic quality of the interfaces impacted in the same way according to the participative method implemented?

The results again showed two different gaps between participatory methods according to subjective and objective measures (Table 2).

On the subjective side, the difference between concepts resulting from the two PD methods was very marked. The individual concept was perceived as more usable and acceptable than the PDWS concept. Moreover, drivers strongly preferred their concept (more than half of them ranked it first), while more than half of participants ranked the PDWS concept as the worse concept. On the objective side, gaps between the two participative concepts were smaller. Differences seemed to be isolated on three tasks, as there was no significant difference in term of global efficiency and visual distraction (combined variables on all tasks).

Table 2: Summary of the results for each variable for the differences between the participatory design workshop (PDWS) and the individual participatory design (PDInd) concepts, ns = non-significant, †= trend (.1<p<.05), * = p<.05, ** = p<.01

			PDWS vs PDInd
Usability	Perceived mental effort (RSME)		PDInd better *
	Global usability (SUS)		PDInd better *
	Usability dimensions (Home-made questionnaire based on Nielsen criteria)	Learnability	PDInd better **
		Efficiency	PDInd better **
		Memorability	PDInd better **
		Errors	PDInd better **
		Satisfaction	PDInd better *
Acceptance	Acceptance (Van der Laan)	Utility	PDInd better **
		Satisfaction	PDInd better **
	Global satisfaction	Order of preference	PDInd better *
		Satisfaction score	ns
Efficiency and visual distraction	Global (z-scores; all tasks; combined variables)		ns
	Per task		Task 2: PDWS more efficient * and less distracting ** Task 3: PDInd more efficient ** and less distracting ** Task 7: PDInd less distracting *
Accuracy	Accuracy scores		Task 7: PDInd more accurate †
Driving performances	Average speed		ns
	Speed variability		ns
	Average lateral position		ns
	Lateral position variability		ns

The first consideration regarding these results is that usability, distraction and acceptance are not impacted in the same way between the two participatory methods implemented. Perceived usability and acceptance were clearly better for the PDInd concept than the PDWS concept. On the other hand, the gaps of actual usability and distraction were smaller between concepts. Participatory design covers all methods involving users in the design of the concepts. However, during the design sessions, many aspects can vary such as the roles of users and designers (from facilitator to co-designer; Sanders & Stappers, 2008), the “make-tool” used to design (from papers and pencils to interactive prototypes; Sanders, 2002), the type of workshop activities (from telling to enacting activities; Sanders et al., 2010), or the number of users involved in the workshop (in group or individually; Sanders et al., 2010). Bratteteig and Wagner (2016) stressed that there are many ways of arriving at a participatory design results. This project compared two PD methods, showing differences in term of outcomes quality, suggesting that some PD methods would be more effective than others. This meets the results reported by DeSmet et al. (2016), which highlighted differences in effectiveness of medical serious games according to the participative method implemented. It is therefore essential to investigate further participatory design by considering the variety of methods.

Besides that, these results showed an increased usability and intention to use for personal designs compared to the concept of the workshop in group. Three interpretations are possible. First, as mentioned above, choice-making could have influence the subjective experience. Second, individual design sessions would enable the elicitation of individual particular needs (Fan & Poole, 2006; Sleeswijk Visser et al., 2005) that would be specific to every individual and not shared collectively. Finally, the subset of four users would have failed to translate the needs of actual end users (Mugge, Schoormans, & Schifferstein, 2009). In this sense, the consensus building and collective intelligence processes specific to the workshops in groups (Sanoff, 2007) would not be as beneficial as expected on the outcome.

Another key finding is the differences found regarding subjective and objective results for the PD interfaces. This non-correspondence demonstrated that objective and subjective data should be considered in the evaluation of HMI, the best interface being those that will optimize the two types of data. This result also provides perspectives of research on the link between actual and perceived usability (independent in this study, as suggested by Tractinsky, Katz, & Ikar, 2000). Moreover, the inter-relation between use and acceptance is discussed. Complementary data would be useful to clarify these issues.

This study answered a need for rigorous assessment of PD outcomes. Bossen, Dindler and Iversen (2010) proposed that “user gains” in PD can be indirect (democratic aspect) or more direct (improvement of personal skills or quality of work). Regarding the direct user gains, one of the limitations reported for PD was the lack standardized, reliable, and validated measures of system success, system use, and user satisfaction (Cavaye, 1995; Ives & Olsson, 1981). Many qualitative evaluations of the participatory process were conducted (Bossen et al., 2016) without significant objective and quantitative measures on outcomes quality. In this research, the subjective aspects were measured using several quantitative questionnaires. The results were consistent across questionnaires, demonstrating a good validity of the findings. The objective measures were collected using precise tools. It was even more important regarding that the subjective benefits, widely reported for PD (Kujala, 2003), were not in line with the objective results.

2. Limitations and perspectives

This project rigorously compared different design processes and has brought concrete results on the effects of user involvement in design, which could be useful for HMI researchers and practitioners. Nevertheless, the results must be interpreted in light of some limitations to ensure a global view. In this part, the limitations linked to the object of study (trucks HMI) are firstly exposed. Second, the limitations regarding the design processes conducted are reported. Finally, perspectives are proposed for future research.

2.1.1. Object of study

When implementing participatory design for trucks HMI, some obstacles were faced. Trucks HMI design implied many constraints such as difficulties to use software, HMI are not standard, but rather should be designed for each truck configuration, the design should follow regulations and imply knowledge on technical aspects. In this research, drivers were representative of a subset of drivers (from cluster 1 identified in the first sub-project), worked on a subset of functions (primary driving functions), and did not explore all points addressed by professional designers (e.g. depth of the menus).

Besides that, the three concepts differed in user involvement during the process, but not only. The three resulting concepts were compared in order to indirectly evaluate the design method. However, it would be interesting to identify and specify the parameters that vary between the different concepts, such as the display clutter that can affect visual-search efficiency (Moacdieh & Sarter, 2015) or the efficiency of the chosen representations for each function. It would be for example interesting to select several criteria in order to characterize the distance between concepts. This could help to estimate if the UCD concept had a higher degree of difference with the PDWS concept than with PDInd concepts. Moreover, it would allow to highlight the variables maximizing differences between the concepts (e.g. differences in clutter, layout, sizes, or functions chosen). For this, a Multiple Correspondence Analysis could be conducted.

2.1.2. Design processes

The first limitation regarding the design processes is that other methods could have been tested. Spinuzzi (2005) proposed three criteria to assess the participatory design processes involving industrial workers: quality of life for workers (i.e. improving workers' quality of life both in terms of organizational empowerment and ease of performing their given task), collaborative development (i.e. representative users or average users have to be fully involved, with a determination of a common language and common aims) and iterative process (i.e. continual participation of workers during several stages ensuring a sustained reflection). To transfer this idea to our application case, the criteria would be: better HMI quality, active involvement of drivers, and iterative process through the different stages. The three criteria were respected in this research. However, there are many other ways to collect a UCD outcome (e.g. with others or more designers, other levels of designer expertise, more iterations, more drivers to test concepts) or to achieve a PD result on the same design case (e.g. different roles for users and designers, other design activities, a higher number of drivers involved). It would be interesting to collect data on other UCD and PD processes to validate these findings.

Second, other roles could have been tested. In this project, specific roles were experimented, with a design by users in the strict sense. Indeed, drivers had a full role of designers, and experts a role of facilitators. We experimented these roles because (1) technological advances allowed such roles, (2) it was part of the moral aspect of participatory design (empowerment of users), (3) users' freedom of expression was not hampered by social aspects or technical constraints put forward by the experts, and (4) it opened perspectives for trucks dashboard personalization. Some of the PDInd instrument clusters would never have been produced by experts but resulted in a high driver's satisfaction. It remains therefore an interesting input for designers. However, the ISO 9241-210 (2010) suggests that "the effectiveness of user involvement increases as the interaction between the developers and the users increases". Moreover, Ehn (1993) proposed that the benefits of participatory design would rely on the meeting between users' tacit knowledge and experts' more abstract, analytical knowledge. In this research, this combination of both knowledge may have been missed. A collaboration with equivalent roles of designers for experts and users would allow meeting designers knowledge and skills (e.g. holistic point of view, costs, technical constraints, brand image, human factors and ergonomic knowledge) with user knowledge (e.g. context of use, experience with other brands and devices, more comfortable with trade-offs, individual perspective).

Finally, other tasks could have been used in the evaluation. Indeed, the eleven tasks were selected to match with actions carried out frequently by delivery drivers during their activity. However, this relies on the expert knowledge and experience, and was not quantified thanks to an activity analysis.

2.1.3. Future research

Future research could explore further PD rationales that were questioned in this study. Indeed, PD benefits would rely on the access to users' tacit and latent needs and to users' tacit knowledge. However, this study showed that user-centered design could address users' needs and result in easy to use and safe interfaces. According to Nielsen (2008), three degrees of differences between experts and users can be distinguished. The first level contains developers who are users, meaning that they take part of the target audience. The second level includes developers who understand the product, because they use it themselves and therefore know user's needs. The third level represents the bigger gap between developers and users, when developers conceive for a foreign domain. Trucks HMI experts are in the latter situation (contrary to automotive designers for example). However, the success of the UCD concept may suggest that they also have access to tacit knowledge of users. Indeed, Nonaka, Takeuchi, and Umemoto (1996) proposed a model of knowledge conversion. In this model, they proposed that tacit knowledge can be transmitted to another person thanks to socialization (i.e. practice, guidance, imitation, and observation). Moreover, tacit knowledge would be made explicit through externalization mechanisms (e.g. using metaphor). Therefore, tacit knowledge could be accessed and internalized by experts during the analyses phase in contact with users, their context of use, and their anecdotes (e.g. during activity analyses) and thus be used as input in user-centered design too.

Another perspective for future research is to assess long-term effects of the different levels of user involvement. Clement and Van den Besselaar (1993) reported that there is little data on the long-term effects of PD. Because of time constrains, this aspect was not addressed in this research. Nevertheless, these data are essential to assess the effects of user involvement over time, with potential behavioral adaptations. Moreover, in this study, the delay between individual concepts design and assessment was short. Although it would match the real context of use of personalization, and although this effect was reduced by the familiarization drive with the two other concepts, further studies could increase this delay. Additionally, previous studies reported changes in usability over time (e.g. Guerreiro, Nicolau, Jorge, & Gonçalves, 2009; Sonderegger, Zbinden, Uebelbacher, & Sauer, 2012; Von Wilamowitz-Moellendorf, Hassenzahl, & Platz, 2006). Karapanos, Zimmerman, Forlizzi and Martens (2009) proposed a framework of product use over time with three phases: orientation (user's first experience with the product), incorporation (integration of the product into the user's daily life), and identification (product becomes part of the user's self-identity). He suggested that the first phase would be impacted by the aesthetics and learnability of a product, the second phase by long-term usability and usefulness, and the last phase by social and personal aspects. A long-term study investigating these three phases would also be an interesting indicator of design approaches sustainability.

Finally, individual participatory design experienced in this research opens perspectives toward dashboard personalization. The findings of this research for the individual participatory design sessions clearly meet the perspective of truck dashboards personalization. Fan and Poole (2006) reported that one way to make the most out of the individual user's needs is to let the user explicitly personalize the product. Moreover, Normark (2015) proposed an experimental setup close to that of this research to investigate a touch-based customizable in-vehicle user interface. They reported a positive effect on drivers' subjective experience. The results of the present research showed a high usability and acceptance score for individual concepts, corroborating this idea. However, contrary to what Marcus (2004) hypothesized, individual concepts did not result in faster and safer task completion compared to user-centered design. Further research could explore the effects of different dashboard customization levels on efficiency and distraction criteria.

3. Recommendations to practitioners

Two key findings were reported in this project for practitioners. First, it is essential to keep investing efforts in user-centered design. Indeed, this research demonstrated that UCD can result in usable, accepted, and safe instrument clusters. Moreover, the UCD concept was globally better than both PD outcomes (subjective and objective measures combined). To express it more amusingly, professionals cannot yet put foot on their desk, users are not ready to do their job for them. However, it is important to highlight that concepts are the results from the designers' interpretations of the users' needs and requirements. User involvement should be carefully and rigorously implemented during the analyses and assessment phase. Indeed, it is important to keep in mind that the quality of an interface is impacted in part by what designers know – or not know – about users (Weinschenk, 2011). Second, even if results were not concluding regarding objective measures, participatory design should not be thrown in the trash. This project showed that participatory outcomes can be perceived as usable and accepted (PDInd concepts). Additionally, this study explored only part of the possibilities offered by participatory design (e.g. specific roles). Future research will help to determine more precisely what participatory design can offer. It is also important to stress the findings of these study do not reduce the weight of other benefits such as new knowledge, skills, or collaborations (Bratteteig & Wagner, 2016).

Conclusion

The benefits of participatory design in other fields brought perspectives for optimizing the ergonomic quality of trucks HMI. Using a tactile prototyping tool on a driving simulator, three concepts of instrument clusters were generated. User-centered design corresponded to a consultative level of involvement. Two participatory methods have been implemented: a collective workshop and individual sessions, corresponding to a participative level of involvement. The results did not demonstrate that participatory design had a significant impact on usability, distraction and acceptance. The user-centered design concept has proven to be more efficient, safer, and so – or more – usable and acceptable than participatory concepts. In addition, differences were reported between the two participatory methods implemented, calling for a more rigorous consideration of the methods used. Finally, the results demonstrated the importance of measuring the subjective and objective aspects, which proved to be independent and complementary. At a higher level, these results questioned users' ability to decide for them, and invite to investigate further the underlying determinants of the subjective benefits reported for participatory design. For example, if benefits were based solely on the possibility to choose and make decision, proposing several concepts designed by experts would be sufficient to improve the user experience without weakening the objective aspects. What Marcus wrote in 2004 is still true: “the road ahead is a wide and challenging one”.

Résumé substantiel en français

1. Présentation

Ce projet de recherche avait pour objectif d’étudier comment le niveau d’implication des conducteurs dans le processus de conception des interfaces homme-machine poids-lourd impacte l’utilisabilité, la distraction, et l'acceptation. Ce résumé présente dans un premier temps l’objet d’étude (i.e. les interfaces poids-lourd, la conception centrée sur l’humain, et l’implication des utilisateurs). Dans un second temps, l’état de la connaissance actuelle sur la conception participative est exposé, en insistant sur les points restants à explorer. Enfin, les objectifs et la structure de ce projet sont présentés.

1.1. Objet d’étude

Les Interfaces Homme-Machine (IHM) définissent tous les dispositifs permettant la communication entre une technologie et son utilisateur. Dans un camion, le conducteur peut agir sur le véhicule (e.g. boutons permettant au conducteur d'engager une fonction du véhicule), et le véhicule fournit des informations au conducteur à travers les interfaces (e.g. afficheur du tableau de bord affichant des informations telles que la vitesse).

Les IHM poids-lourd présentent plusieurs spécificités :

- Elles sont principalement utilisées pendant la conduite. Afin d’éviter de potentiels risques de sécurité routière, les interfaces poids-lourd doivent être conçues pour minimiser la distraction des conducteurs. Cela consiste à réduire autant que possible le temps passé avec les yeux en-dehors de la route, la durée avec les mains en dehors du volant, et la charge mentale impliquée par l’interaction avec l’interface. Marcus (2004) illustre bien ce défi de conception en exprimant : « Imaginez avoir à penser à la sécurité, à l'utilisabilité et à l'esthétique de l'interface utilisateur d'un appareil mobile de deux tonnes qui traverse l'espace à 100 km/h. Maintenant, vous avez l'image en tête » (p. 91).
- Avec les avancées technologiques, les informations à afficher aux conducteurs sont de plus en plus nombreuses et complexes (Gkouskos, Normark, & Lundgren, 2014). Afin d’éviter les erreurs humaines lors de l’interaction avec un système, les interfaces doivent être conçues de façon utilisable. Les concepteurs doivent sélectionner les informations pertinentes à présenter au conducteur, déterminer le mode d’affichage, et spécifier une logique d'interaction qui assure un accès à l’information facile, rapide et sans erreur.

- Dans les camions actuels, les mêmes interfaces sont utilisées dans différents contextes. En effet, la même IHM est conçue pour une gamme complète de véhicules. Dans ce projet, nous nous sommes concentrés sur une gamme spécifique de camions : les camions de distribution (Multi-purpose vehicles [MPV]). Ce sont des véhicules entre 10 et 26 tonnes destinés principalement à la distribution de biens ou à la construction légère (e.g. la livraison d'équipements sur des chantiers). Ils sont différents des véhicules « long-routiers », principalement destinés au transport longue distance ou à la construction lourde. Les camions de distribution sont utilisés dans de multiples contextes d'utilisation impliquant des besoins divers en termes d'IHM. Par exemple, le même tableau de bord peut être utilisé par un pompier conduisant à grande vitesse ; par un conducteur de distribution novice qui conduit en centre-ville entouré de piétons ; ou par un conducteur âgé réticent aux nouvelles technologies qui conduit un porte-voitures sur autoroute. Par conséquent, en plus d'être faciles à utiliser et non-distrayantes dans tous les contextes d'utilisation, les IHM MPV doivent couvrir tous les besoins des utilisateurs dans les différents contextes d'utilisation afin de garantir une bonne acceptation de la part des conducteurs.

Il y a vingt ans, la conception des interfaces homme-machine poids-lourd dépendait principalement des caractéristiques et des contraintes imposées par la technologie sous-jacente. Néanmoins, l'accroissement des dispositifs à bord du véhicule et les enjeux de sécurité routière ont provoqué un changement d'une conception techno-centrée vers une conception anthropocentrée. La conception centrée sur l'humain est une approche visant à concevoir des produits utiles et utilisables (ISO 9241-210, 2010). La conception est axée sur les caractéristiques de l'humain, les besoins, et les attentes des utilisateurs. L'objectif est d'améliorer le confort des utilisateurs et d'atténuer les potentiels effets négatifs liés à l'utilisation d'un système (e.g. les risques sécuritaires). Les processus de conception centrée sur l'humain se divisent en différentes phases. La première phase est une phase d'analyse. Elle consiste à identifier et spécifier le contexte d'utilisation et les contraintes liées aux utilisateurs. Dans une deuxième phase, plusieurs concepts sont conçus sur la base des données de la phase précédente. La troisième phase est une phase d'évaluation dans laquelle les concepts générés sont comparés aux critères requis. Sur la base des résultats de cette phase, plusieurs itérations peuvent être réalisées avec les phases précédentes.

L'un des principes de la conception centrée sur l'humain est une participation active des utilisateurs (Maguire, 2001). Il est désormais reconnu que la participation des utilisateurs au processus de conception est une source précieuse de connaissances sur le contexte d'utilisation, les tâches, les besoins, les attentes des utilisateurs, et sur leur réaction à un nouveau produit (Bekker & Long, 2000 ; Rogers, Sharp, & Preece, 2011). Cependant, la nature et la fréquence de cette participation des utilisateurs peuvent varier selon les approches de conception implémentées. On peut distinguer trois niveaux de participation des utilisateurs dans le processus de conception :

- L'utilisateur peut être considéré comme une source de données. Eason (1995) caractérise ce niveau comme une conception pour les utilisateurs. Le type de participation est informatif (Damodoran, 1996).
- L'utilisateur peut être impliqué afin d'évaluer des concepts. Ce niveau correspond à une participation consultative (Damodoran, 1996), dans un processus de conception avec les utilisateurs (Eason, 1995).
- L'utilisateur peut participer à la phase de conception. C'est le niveau d'implication participatif (Damodoran, 1996) qui correspond à une conception par les utilisateurs (Eason, 1995).

Un point-clé de l'implication des utilisateurs est souligné par Damodoran (1996) : les niveaux de participation n'ont pas de limites strictes, et peuvent être caractérisés comme étant sur un continuum partant d'une implication informative, puis consultative, et enfin participative.

Les approches centrées sur l'humain sont multiples. Cependant, les deux principales approches centrées sur l'humain sont : la conception centrée sur l'utilisateur (UCD) et la conception participative (PD) (Bekker & Long, 2000). Sur la base des différents niveaux de participation des utilisateurs, les deux approches peuvent se différencier ainsi (Bekker & Long, 2000 ; Bratteteig & Wagner, 2016 ; Carroll, 1996 ; Kujala, 2003 ; Sanders, 2002 ; Spinuzzi, 2005) :

- La conception centrée sur l'utilisateur (UCD) correspondrait à une conception pour et avec les utilisateurs, avec des formes d'implication informatives et consultatives. En effet, les utilisateurs participent d'abord à la phase d'analyse, avec des techniques telles que des enquêtes, des entretiens, ou des analyses d'activité. Ils sont également impliqués pendant la phase d'évaluation, où les experts en IHM observent comment ils réagissent aux concepts et recueillent leurs commentaires (tests d'utilisabilité). Les utilisateurs ne sont cependant pas impliqués lors de la phase de définition des concepts, ces derniers étant conçus par les experts.

- La conception participative (PD) correspondrait à une conception par les utilisateurs, avec une implication participative. Les utilisateurs sont impliqués tout au long du processus de conception. Ils participent non seulement aux phases d'analyse et d'évaluation, mais également lors de la définition des concepts. Au cours de cette phase, des techniques telles que des activités narratives, des journaux d'activités, des cartes mentales, ou des activités de prototypage sont utilisées.

Aujourd'hui, la conception centrée sur l'utilisateur est largement utilisée pour la conception des IHM poids-lourd (e.g. Engström et al., 2006 ; Hesse et al., 2011 ; Marberger, Dangelmaier, Widlroither, & Bekiaris, 2004). Cependant, certains auteurs recommandent une implication croissante des utilisateurs dans le processus de conception (Marcus, 2004 ; Sanders & Stappers, 2008). La conception participative ouvrirait ainsi des perspectives intéressantes.

1.2. Etat de la connaissance

Maguire (2001) a résumé les avantages de la conception centrée sur l'utilisateur :

- Augmentation de la productivité : réalisation des tâches sans sollicitation de ressources temporelles ou cognitives inutiles ;
- Réduction des erreurs : une conception axée sur l'utilisabilité permet d'éviter les incohérences, les incompréhensions, ou d'autres défauts entraînant des erreurs ;
- Réduction de la formation et de l'assistance : en produisant des produits plus utilisables, la conception centrée sur l'utilisateur réduit le temps d'apprentissage et la nécessité d'assistance ;
- Amélioration de l'acceptation : la considération des besoins de l'utilisation, et les évaluations réalisées en amont permettent d'augmenter l'intention d'usage et la confiance des utilisateurs ;
- Réputation de l'entreprise : bénéfice d'un point de vue marketing sur l'image de la marque.

Lors de la définition des concepts, les experts prennent leurs décisions selon plusieurs facteurs : les facteurs humains, les coûts, le planning des projets, l'image de la marque, etc. Ils adoptent une vision holistique et complète, en tenant compte de tous les usages, des configurations de véhicules, mais également des différentes configurations d'IHM possibles. Par exemple, lors de la définition d'une interface promouvant l'écoconduite :

- Les indicateurs doivent être pertinents pour tous les environnements de conduite et les différentes charges de véhicules ;

- Les informations affichées doivent être suffisamment détaillées pour un éco-conducteur expérimenté mais également faciles à comprendre pour un conducteur novice ;
- La disposition des informations doit être aussi adaptée pour un camion possédant un régulateur de vitesse adaptatif que pour un camion dénué d'options.

Les considérations des experts sont donc globales et non individuelles.

Néanmoins, certaines limitations peuvent être adressées à la conception centrée sur l'utilisateur. Tout d'abord, le fort niveau de contrôle est critiqué (Lee, 2008). En effet, les concepts d'IHM sont créés par des experts et les utilisateurs ne sont uniquement consultés pour les évaluer. La conception UCD se concentre donc principalement sur la façon dont l'utilisateur réagit à un concept et omet ce qu'il pourrait apporter lors de la définition des concepts. Deuxièmement, la conception centrée sur l'utilisateur peut être facilement applicable et exhaustive sur des projets présentant peu de contraintes. Par exemple, lors de la définition d'une nouvelle commande d'essuie-glace, le nombre de configurations d'IHM différentes est limité. Toutes les configurations possibles pourraient être testées lord d'un test d'utilisabilité afin de s'assurer de la configuration la plus adaptée. Cependant, les progrès technologiques apportent une nouvelle flexibilité dans la conception d'IHM. Si les commandes d'essuie-glace devaient être présentées sur un écran tactile, le nombre de représentations, de tailles, de dispositions ou d'informations à afficher augmenterait, et toutes les configurations seraient moins susceptibles d'être traitées de manière exhaustive dans un test d'utilisabilité. Ce défi de conception est particulièrement d'actualité avec l'arrivée des tableaux de bord de type écran. Troisièmement, la qualité d'une interface est affectée en partie par ce que les concepteurs connaissent – ou ne connaissent pas – des utilisateurs (Weinschenk, 2011). Cependant, les recommandations facteurs-humains et les connaissances ergonomiques sont nombreuses mais non exhaustives. Collecter des informations sur le contexte d'utilisation, sur le ressenti des utilisateurs, et sur leur réaction à des prototypes est coûteux temporellement et ne pourrait objectiver toutes les décisions de conception à réaliser.

Il serait évident de répondre à ces limites si les utilisateurs savaient ce dont ils ont besoin, et ce qu'ils traiteraient facilement et efficacement. Si c'était le cas, les impliquer dans la conception permettrait de gagner du temps et d'optimiser la qualité des interfaces. En d'autres termes, si les utilisateurs savent ce dont ils ont besoin et ce qu'ils traiteraient facilement et efficacement, ils devraient participer directement lors de la conception, pour éviter que les experts passent du temps à essayer de comprendre ce dont ils ont besoin et ce qu'ils traitent facilement.

Concernant la conception participative, ses principaux avantages sont résumés par Damodaran (2006) :

- Amélioration de la qualité du produit grâce à une meilleure définition des besoins des utilisateurs ;
- Non-implémentation de caractéristiques coûteuses dont les utilisateurs n'ont pas besoin ou n’utilisent pas ;
- Amélioration de l’acceptation des utilisateurs ;
- Amélioration de la compréhension des utilisateurs ;
- Participation accrue à la prise de décisions.

Deux raisons encouragent le changement vers une conception participative (Carroll & Rosson, 2007) : un aspect moral (i.e. les utilisateurs ont le droit d'être impliqués dans la prise de décision) et un aspect pragmatique (i.e. l'expérience et les connaissances des utilisateurs peuvent offrir des idées pour la conception). L'aspect moral réfère aux origines de la conception participative. En effet, la conception participative est apparue dans les pays scandinaves dans les années 70 et 80 (Ehn, 1993 ; Floyd, Mehl, Reisin, Schmidt, & Wolf, 1989). Elle a été mise en place lors de l’introduction des ordinateurs dans les espaces de travail. Des collaborations entre chercheurs, syndicats, et travailleurs ont été menées afin d’accompagner ce changement (Spinuzzi, 2005). L'aspect pragmatique de la conception participative présente des avantages potentiels sur la qualité ergonomique des interfaces. Ces avantages reposeraient sur deux facteurs. Les utilisateurs ont différents niveaux de besoins (i.e. explicites, observables, tacites, et latents) y compris des besoins implicites qui ne peuvent être exprimés par la parole ou lors de l’utilisation d’un prototype (Sanders, 2002). En concevant activement un concept, les utilisateurs fourniraient un accès direct à ces besoins, menant à des produits plus utiles et donc plus acceptés. Lors de l’interaction avec une interface, les utilisateurs impliqueraient également des connaissances tacites (i.e. des connaissances implicites). Par exemple, lorsqu’on présente un nouveau tableau de bord à un conducteur, la direction de son premier regard va dépendre de plusieurs facteurs généraux et individuels, tels que sa culture (e.g. sens de lecture de la langue), les processus cognitifs (e.g. une information qui clignote en vision périphérique va attirer son attention), et ce qu'il s’attend à voir en fonction de ses expériences passées et de ses connaissances tacites. Même si les aspects généraux peuvent être abordés à travers les directives de conception facteurs-humains, les recommandations ergonomiques, et les activités explicites ; les aspects implicites et individuels sont plus difficilement accessibles. Lors d’une conception participative, comme l'utilisateur est également le concepteur, il utiliserait directement ses connaissances implicites en tant que ressources. Par exemple, au cours de sa carrière, un conducteur de camion a interagi avec plusieurs tableaux de bord de différentes marques. Sur cette base, il a construit un modèle mental de tableau de bord, avec ce qu'il s’attend à voir et où il s’attend à le voir. En interagissant avec un nouveau tableau de bord, il s'appuiera sur ce modèle mental. Par conséquent, si les interfaces ne correspondent pas aux représentations mentales des conducteurs, elles peuvent entraîner une mauvaise utilisation, de potentiel risques, ou un rejet du système (Carroll & Olson, 1987). Les connaissances tacites impliquent une grande variabilité interindividuelle pour l'interaction avec les IHM. Ces connaissances, acquises par les conducteurs grâce à l'expérience et l'automatisation des processus, sont donc essentielles pour répondre aux besoins des utilisateurs. Tenir compte des aspects implicites permettrait de produire des interfaces plus faciles à utiliser et plus efficaces (et, par conséquent, moins distrayantes).

Sur la base de la littérature existante, certains points restent à explorer. Tout d'abord, la tendance actuelle s’oriente vers une implication de plus en plus accrue des utilisateurs (Marcus, 2004 ; Sanders & Stappers, 2008). Cependant, il existe un manque de preuves empiriques et rigoureuses en faveur de cela. En effet, même si des avantages ont été rapportés suite à des projets participatifs, ceux-ci n’ont pas été comparés aux potentiels avantages collectés avec une conception centrée sur l'utilisateur sur le même cas d’étude. Deuxièmement, il existe de nombreuses évaluations des processus de développement participatifs (Bossen, Dindler, & Iversen, 2016), mais peu d'évaluations rigoureuses des résultats de ces processus. Bratteteig et Wagner (2006) ont insisté sur la nécessité de passer d’une évaluation des processus à une évaluation des résultats. Troisièmement, les avantages sont souvent attribués globalement à la conception participative. Néanmoins, il existe de nombreuses manières d’arriver à un résultat participatif (Bratteteig & Wagner, 2016). Les différentes méthodes de conception participative peuvent différer en termes de coût, de ressources utilisées, de temps passé, etc. Les différences en termes de résultats devraient recevoir l’attention appropriée afin de guider les praticiens vers les meilleures méthodes à utiliser. Enfin, contrairement à d'autres types d'interfaces où les critères subjectifs peuvent prévaloir sur les critères objectifs, l'efficacité et la distraction des tableaux de bord sont essentiels pour la sécurité routière. Il est nécessaire de mesurer rigoureusement les effets de la conception participative sur les aspects d'efficacité et de distraction. Cet aspect est d’autant plus actuel dans une perspective de personnalisation des tableaux de bord (Marcus, 2004).

1.3. Objectifs

Cette thèse vise à améliorer les connaissances sur la manière la plus efficace d'impliquer les conducteurs routiers afin de créer des interfaces faciles à utiliser et sécuritaires. La mise en œuvre de deux méthodes participatives sur un cas d'application concret permet d'expérimenter concrètement ces méthodologies et de répondre aux questions suivantes : les conducteurs savent-ils ce qu'ils veulent et ce qu'ils traiteront bien (d'un point de vue cognitif), c'est-à-dire ont-ils des méta-représentations correctes de ce qu'ils pourraient utiliser efficacement et de façon sécuritaire. Si c'était le cas, la conception participative pourrait avoir un impact positif sur l'utilisabilité, la distraction, et l'acceptation des interfaces. De plus, il existe une variété de méthodes participatives qui peuvent être mises en œuvre, nécessitant des ressources différentes (i.e. temps, coût, personnes impliquées). L'étude de l'impact de la méthode participative utilisée sur la qualité des concepts générés est fondamentale pour les praticiens. En outre, l'un des objectifs était d'enrichir les connaissances des praticiens pour la conception centrée sur l'utilisateur, en fournissant une analyse du contexte d'utilisation des IHM MPV, en synthétisant les recommandations ergonomiques existantes, et en les enrichissant avec de nouvelles études.

Plus précisément, cette thèse a pour objectif de répondre aux questions de recherche suivantes :

- Comment le niveau de participation du conducteur dans le processus de conception affecte-t-il l'utilisabilité, la distraction, et l'acceptation des IHM poids-lourd ?
- La qualité ergonomique des interfaces est-elle impactée de la même manière selon la méthode participative mise en œuvre ?

Avant tout, un état de l'art a été réalisé. L'objectif de cet article était de résumer les différents bénéfices obtenus pour la conception participative dans d'autres domaines, et de les mettre en regard avec les défis actuels de la conception d'IHM. Cette première étape a permis de définir les objectifs et la structure du projet.

Puis, cette recherche a été divisée en trois sous-projets, suivant les trois étapes de la conception centrée sur l'humain : l'analyse du contexte d'utilisation, la définition des concepts, et l'évaluation des concepts. Ils ont été menés de façon séquentielle, chaque sous-projet utilisant des données des activités précédentes.

Dans un premier sous-projet, l'objectif était d'identifier et de spécifier le contexte d'utilisation des IHM MPV. Cela comprend une analyse des véhicules et des utilisateurs sur lesquels cette thèse s'est concentrée. En effet, la conception centrée sur l'humain nécessite de prendre en compte certaines informations telles que les configurations IHM avec lesquelles les utilisateurs interagissent, leurs tâches, l'environnement d'utilisation, et les caractéristiques des utilisateurs. Ces données ont permis de déterminer le cadre de l'activité de conception et de déterminer les conducteurs à impliquer pour la conception participative.

Dans un second sous-projet, trois processus de développement parallèles ont été menés sur le même cas de conception et avec le même équipement :

- Un processus de conception centrée sur l'utilisateur (user-centered design [UCD]) a d'abord été mené (i.e. implication consultative). Afin de fournir des données d’entrées aux experts, un examen préliminaire des recommandations facteurs-humains a été réalisé, ainsi que trois études visant à compléter ces recommandations (portant sur la définition des compteurs de vitesse et des jauges). Des conducteurs ont évalué trois concepts conçus par les experts afin d’atteindre un concept finalisé : le concept UCD.
- Un atelier de conception participative collectif (participatory design workshop [PDWS]) a été réalisé avec quatre conducteurs poids-lourd professionnels (i.e. implication participative). Les différentes activités réalisées au cours de cet atelier d'une journée ont conduit à la réalisation d'un concept collectif : le concept PDWS.
- Des séances de conception participative individuelle (individual participatory design [PDInd]) ont été réalisées avec vingt-sept conducteurs. Chaque conducteur a pu définir son propre concept et l'a évalué itérativement dans une situation de conduite simulée. Vingt-sept concepts individuels ont donc été recueillis (concepts PDInd).

Le troisième sous-projet avait pour objectif d’évaluer et de comparer les concepts résultant des trois processus menés dans le deuxième sous-projet. Les vingt-sept conducteurs ont évalué le concept UCD, le concept PDWS, et leur propre concept. L'utilisabilité, la distraction et l'acceptation ont été mesurées sur un simulateur de camion avec des scénarios et des tâches prédéfinis impliquant l'utilisation des interfaces.

2. Principaux résultats et discussion

2.1. Etat de l’art

Au début de ce projet, un état de l'art a été mené afin d’examiner les avantages de la conception participative au regard des défis actuels de la conception des IHM. Cet article offre une vision globale de la conception des IHM dans un cadre holistique et pratique. L'approche conventionnelle de la conception des interfaces automobiles a été présentée et les limites de la conception centrée sur l'utilisateur ont été mises en lumière. La conception participative a été proposée comme une alternative potentielle, déjà utilisée dans d'autres domaines de la recherche facteurs humains. Un argument important pour l'emploi de la conception participative semble être que cette approche permettrait d'accéder aux connaissances tacites des conducteurs, avec un potentiel impact positif sur l'utilisabilité et la distraction des interfaces. L'accès aux besoins implicites des conducteurs pourrait également améliorer l'acceptation des interfaces. En outre, un manque d'évaluation formelle a été souligné, avec la nécessité de procéder à une comparaison entre les différents niveaux de participation de l'utilisateur afin de mesurer les écarts en termes de qualité ergonomique des résultats. Les limites potentielles de la conception participative ont également été mises en évidence afin d'assurer une vision globale (i.e. un manque de rigueur méthodologique, une faible validité de l'évaluation des processus, et une remise en cause de la capacité des utilisateurs à ajouter de la valeur dans la phase de conception). Le résumé de la littérature sur la conception participative et la mise en lumière d'une alternative potentielle pour faire face aux défis de conception actuels pourraient être utiles aux chercheurs et aux praticiens.

2.2. Sous-projet 1 : Analyse du contexte d'utilisation

Dans les processus de conception centrée sur l'humain, la connaissance du contexte d'utilisation est une contribution essentielle (i.e. les caractéristiques des utilisateurs, les tâches et l'environnement dans lequel les systèmes sont utilisés). Dans ce projet, l'objectif était de concevoir et d'évaluer des concepts à partir de différentes approches centrées sur l'humain. Par conséquent, une analyse préalable du contexte d'utilisation a été menée à travers deux études.

La première étude était une analyse des camions MPV en termes d'usages, d'activités, et d'environnement d'utilisation. Les données quantitatives, provenant d'une base de données de plus de 5 000 camions, ont été collectées et analysées. Les résultats ont montré que les usages et les applications MPV sont divers. Différentes analyses de données ont permis de regrouper les véhicules en quatre groupes. Le premier groupe, représentant 60% des véhicules, a été choisi comme cible pour les activités de conception. Dans ce groupe, les véhicules étaient principalement équipés de carrossages de type fourgons et frigorique, et utilisés pour des livraisons locales et régionales. Dans ce sens, l'évaluation du troisième sous-projet a été menée dans un contexte urbain et péri-urbain. En outre, les conducteurs impliqués dans les séances de conception participative étaient des professionnels de la distribution locale et régionale. Les données de cette étude ont également montré que les configurations de boutons sur le tableau de bord différaient significativement d'un véhicule à l'autre. Le tableau de bord, commun à tous les véhicules, a donc été choisi comme cas de conception. La configuration d'interfaces de ces camions était basique et comportait principalement des fonctions de conduite. Lors des activités de conception, les fonctions principales de conduite ont donc été investiguées. La principale limitation de cette étude était que les données disponibles indiquaient la présence ou non d'une fonction dans les véhicules. Cependant, la présence ou l'absence de fonctions ne renseigne pas sur leur fréquence d'utilisation, bien que cette mesure soit déterminante pour la conception des IHM. Une analyse d'activité pourrait ainsi compléter cette étude par des mesures de fréquence d'utilisation pour chaque partie des IHM.

La deuxième étude présentait les résultats d'un questionnaire ayant pour objectif d'améliorer la connaissance des conducteurs MPV. Soixante-huit conducteurs ont répondu à un questionnaire sur leur profil, leur travail, leur IHM actuelle, et leurs attentes pour les interfaces futures. Les résultats ont montré que les conducteurs MPV étaient plutôt expérimentés (ce qui suggère qu'ils connaissent bien les fonctions des interfaces) et qu'ils étaient globalement à l'aise avec la technologie (et les smartphones). Sur cette base, le choix d'un outil de prototypage tactile a été conforté. Les questions visant à prioriser leurs besoins et leurs attentes en matière d'IHM ont mis en évidence cinq fonctions importantes : le régulateur de vitesse, les informations sur les temps de conduite, les informations de consommation de carburant, le GPS, et la caméra de recul. Ces données ont été utilisées par les experts dans le processus de conception centrée sur l'utilisateur. En effet, les informations liées aux temps de conduite et au régulateur de vitesse ont été priorisées. Les résultats de l'enquête ont également montré que les conducteurs MPV étaient majoritairement des hommes de 18 à 66 ans. Cette information a été utilisée pour la sélection des conducteurs participant aux activités participatives, afin d'assurer une bonne représentativité des utilisateurs finaux. Ce sondage était innovant dans sa manière d'accéder aux conducteurs (i.e. par Facebook et dans un centre de formation). Cependant, la limite principale de cette étude était la taille de l'échantillon (68 répondants). Cela n'a pas permis d'effectuer des analyses de données plus poussées (e.g. pour l'élaboration de personas quantitatifs ; Maguire, 2001).

Ces résultats ont apporté une représentation synthétique des utilisateurs et des usages. De plus, les techniques quantitatives utilisées pour l'analyse du contexte d'utilisation peuvent être transférées à d'autres domaines.

2.3. Sous-projet 2 : Définition des concepts

2.3.1. *Conception centrée sur l'utilisateur*

La conception centrée sur l'utilisateur était l'un des trois processus de conception menés en parallèle dans cette étude et dont le concept a été évalué dans le troisième sous-projet. Ce concept correspondait à un niveau de participation consultatif (i.e. les conducteurs évaluent les concepts conçus par des experts). Pour cela, les experts ont besoin de données d'entrée afin de définir les concepts. Les données du premier sous-projet ont été utilisées et un travail a été mené sur les recommandations ergonomiques.

En effet, un examen des recommandations facteurs humains existantes a d'abord été mené. Ce document a rassemblé la documentation existante dans laquelle des directives ou des recommandations étaient présentées pour promouvoir l'utilisabilité lors de la conception des interfaces. La vision synthétique offerte par ce document pourrait être utilisée dans l'industrie automobile.

De plus, des expériences ont été conduites dans cette thèse dans le but de compléter les recommandations existantes. Tout d'abord, deux expériences ont permis d'étudier le moyen le plus efficace et satisfaisant d'afficher le compteur de vitesse sur des tableaux de bord de type écrans. Une première étude comparant un compteur de vitesse numérique et un compteur de vitesse analogique a répliqué les résultats existants de la littérature (i.e. le meilleur compteur de vitesse dépend de la tâche effectuée). Sur cette base, une deuxième étude a évalué et comparé les compteurs de vitesse conventionnels et un compteur de vitesse redondant sur des cas d'utilisation contemporains. Deuxièmement, une expérience sur la définition des jauges a comparé huit jauges mélangeant différents attributs (i.e. forme, orientation, et indicateur). Les résultats ont montré que le temps de regard en dehors de la route peut être diminué de 280 ms en changeant la représentation d'une jauge, et de plus de 600 ms lorsqu'un compteur de vitesse redondant est présenté au lieu d'un compteur de vitesse analogique. Ces résultats soulignent la nécessité de mener des études sur les facteurs humains afin de concevoir des interfaces plus efficaces et plus sûres.

Ces données ont été utilisées par les experts lors de la conception centrée sur l'utilisateur. Par exemple, le compteur de vitesse choisi dans le concept UCD était un compteur de vitesse redondant. Cependant, il était intéressant de noter que les experts ont dû choisir entre des principes ergonomiques qui entraient en compétition. En effet, d'une part, les jauges de type linéaire-verticale-remplissage ont été mesurées comme moins efficaces, plus distrayantes et moins satisfaisantes pour la lecture qualitative qu'une jauge linéaire-horizontale-pointeur. D'autre part, les documents existants recommandent que la représentation choisie supporte les modèles mentaux de la réalité des conducteurs (Ross et al., 1996). Par conséquent, des jauges de type linéaire-vertical-remplissage ont été choisies par les experts pour les niveaux de carburant et d'additifs, comme des réservoirs qui se rempliraient. Les experts ont d'abord généré trois concepts et ont invité neuf conducteurs internes à les évaluer. Ensuite, les experts ont redessiné un concept final. Cependant, certaines faiblesses peuvent être soulignées concernant la démarche adoptée dans cette thèse (i.e. peu de conducteurs lors de l'évaluation et pas d'itération).

2.3.2. Conception participative

Deux processus de conception participative ont été menés, différant par le nombre de conducteurs impliqués lors de la session de conception. Premièrement, un atelier collectif a été réalisé avec quatre conducteurs poids-lourd professionnels. Deuxièmement, des séances de conception individuelle ont été menées. Les concepts résultants ont été comparés au concept de conception centrée sur l'utilisateur dans le troisième sous-projet.

En ce qui concerne la mise en œuvre de la conception participative pour la conception des interfaces poids-lourd, l'une des limitations adressées à la conception participative était la diversité des pratiques utilisées, sans méthodologie formalisée (Haines, Wilson, Vink et Koningsveld, 2002 ; Pilemalm & Timpka, 2008 ; Spinuzzi, 2005). Pour surmonter cette limitation, Spinuzzi (2005) a proposé une méthodologie composée de trois étapes : exploration initiale du travail, processus de découverte, et prototypage. Dans cette recherche, les trois étapes ont été appliquées : le premier sous-projet d'analyse correspondait à l'étape 1, les activités narratives correspondaient à la phase 2 et les séances de conception autour de l'outil de prototypage correspondaient au stade 3. De plus, un intérêt particulier a été apporté à l'outil de prototypage, indispensable pour permettre aux utilisateurs de s'exprimer (Sanders, 2002). L'écran tactile semble être un outil visuel et projectif approprié pour faciliter l'échange (déjà utilisé par Normark, 2015). De plus, l'utilisation combinée avec le simulateur de conduite a permis aux utilisateurs d'itérer entre la conception et l'évaluation. Bruno et Muzzupappa (2010) ont signalé que, dans de nombreuses études participatives, la maquette physique du concept apparaît souvent tardivement. Dans cette étude, les « activités de conception » et les « activités de contextualisation » (Sanders et al., 2010) ont été mélangées pour contextualiser les conceptions. Cela a apporté de la validité aux concepts définis par les conducteurs, en effet, ils ne consistaient pas uniquement en un enchaînement d'idées ou de dessins irréalisables comme cela peut être le cas dans des ateliers participatifs de type papier-crayon.

Une autre limitation potentielle souvent rapportée pour la conception participative est la différence entre participation et implication. En effet, Barki et Hartwick (1994) ont souligné que la participation des utilisateurs n'est pas toujours un facteur d'implication. Ils ont clarifié les deux notions ainsi : la participation se réfère à « un ensemble de comportements ou d'activités réalisés par les utilisateurs dans le processus de développement du système », alors que l'implication serait définie comme « un état psychologique subjectif reflétant l'importance et la pertinence personnelle d'un système pour l'utilisateur ». Dans cette étude, des mesures d'implication des utilisateurs ont été effectuées (échelle utilisée dans l'étude de Hunton et Beeler, 1997, sur la base du questionnaire original de Barki et Hartwick, 1994). Pour les deux méthodes participatives, les scores d'implication des utilisateurs - basés sur les dimensions d'importance et de pertinence personnelle - étaient élevés (valeurs proches de 6 sur une échelle de 7 pour les deux concepts). De même, l'attitude de l'utilisateur (> à 5,67), l'auto-efficacité perçue (> à 5,93) et la participation souhaitée (> à 6,56) ont recueilli des scores élevés. Avec les deux méthodes, les conducteurs ont donc rapporté un niveau d'implication élevé.

2.4. Sous-projet 3 : Evaluation des concepts

Le but de ce sous-projet était d'évaluer et de comparer les trois concepts de tableaux de bord en termes d'utilisabilité, de distraction, et d'acceptation. Vingt-sept conducteurs ont évalué le concept UCD, le concept PDWS, et leur propre concept. L'utilisabilité, la distraction et l'acceptation ont été mesurées sur un simulateur de conduite à l'aide de scénarios et de onze tâches prédéfinies impliquant l'utilisation des interfaces. Des études antérieures avaient déjà comparé des approches centrées sur l'humain (Bekker & Long, 2000 ; Carmel et al., 1993 ; Carroll, 1996). Cependant, ces comparaisons étaient plus théoriques, visant à définir les limites et les spécificités des approches. Bratteteig et Wagner (2006) ont insisté sur la nécessité de passer d'une évaluation des processus à une évaluation des résultats. Ici, les deux approches centrées sur l'humain ont été comparées de manière systématique sur le même cas de conception et avec le même équipement. Ce qui différenciait les résultats des trois processus étaient les approches adoptées et les personnes impliquées pour les définir. De plus, l'évaluation a été effectuée de manière rigoureuse en suivant la méthode expérimentale.

2.4.1. Comment le niveau de participation du conducteur dans le processus de conception affecte-t-*il l'utilisabilité, la distraction, et l'acceptation des IHM poids-*lourd ?

Les résultats ont révélé que les interfaces étaient impactées de deux manières différentes.

Tout d'abord, sur les aspects subjectifs (acceptation et utilisabilité perçue), il semble que les effets n'étaient pas liés au niveau de participation du conducteur, mais à l'approche mise en œuvre. En effet, les différences avec le concept UCD n'étaient pas cohérentes entre les deux approches participatives : le concept UCD était plus utilisable et accepté que le concept PDWS, mais n'était pas significativement différent du concept PDInd (scores élevés d'utilisabilité et d'acceptation pour les deux concepts).

Deuxièmement, sur les mesures objectives (efficience et distraction visuelle), le concept UCD était globalement meilleur que les deux concepts participatifs. Le concept UCD impliquait des temps de complétion de la tâche et des temps de regard en dehors de la route plus faibles que le concept conçu lors de l'atelier participatif collectif. Cet effet était global : toutes tâches confondues sur les deux variables combinées (efficience et distraction visuelle). La différence entre les deux concepts s'est révélée significative lors de la réalisation de deux tâches, avec des différences allant jusqu'à 4 870ms / 48% pour les temps de complétion et 3 526ms / 81% pour la réduction de la distraction visuelle (tâche 7 : activer le limiteur de vitesse). De même, bien que la différence soit réduite, le concept UCD a recueilli de meilleurs résultats que les concepts individuels. Toutes tâches combinées, les tâches ont eu tendance à être réalisées plus rapidement et avec un temps de regard en dehors de la route plus faible. Sur trois des tâches, le concept UCD s'est révélé meilleur que les concepts PDInd (tâche 2 : lire la valeur de la vitesse, tâche 5 : comparer la vitesse à 30 km/h, et tâche 7 : activer le limiteur de vitesse). Cependant, l'amplitude des gains était plus faible (gain de 387ms / 18% dans la réalisation de la tâche et 438ms / 50% pour le temps de regard en dehors de la route pour la tâche 2 ; ainsi qu'une tendance statistique uniquement pour la tâche 7). D'autre part, aucune différence significative n'a été trouvée entre les interfaces des deux niveaux d'implication en termes de précision et de performance de conduite.

La littérature existante proposait l'hypothèse selon laquelle le bénéfice pragmatique de la conception participative (Carroll & Rosson, 2007) reposerait sur l'accès aux besoins et aux connaissances implicites des utilisateurs (Sanders, 2002). L'accès aux besoins implicites aurait dû mener à des interfaces plus utiles, et donc plus acceptables. Néanmoins, le concept UCD a recueilli de meilleurs scores d'acceptation que le concept PDWS, et les scores étaient aussi bons que ceux des concepts individuels. L'absence de différence significative pour la dimension de l'utilité du test d'acceptation est également intéressante. En effet, cela signifierait que le concept UCD a répondu aux besoins et aux attentes des utilisateurs. Une autre interprétation pourrait être que les conditions de cette étude n'ont pas permis d'accéder à ces besoins. En effet, les degrés de liberté de conception étaient limités aux fonctions, à la taille, et aux représentations de l'information. En outre, les conducteurs ont préféré le tableau créé pour eux par les experts, plutôt que le tableau de bord créé pour eux par des conducteurs. Les experts, sur la base des activités d'analyse explicites, ont donc une bonne connaissance des besoins des utilisateurs et de leurs attentes. De même, il y a eu peu de différence entre les fonctionnalités incluses dans les tableaux de bord entre le concept UCD et les concepts participatifs (plus de 80% de fonctions communes).

L'accès aux connaissances tacites des utilisateurs aurait dû conduire à des interfaces plus utilisables et moins distrayantes. Cependant, le concept UCD a été perçu comme plus utilisable que le concept PDWS, et les mesures d'utilisabilité et de distraction visuelle étaient significativement meilleures qu'avec le concept PDWS. L'application des recommandations ergonomiques et une conception centrée sur l'utilisabilité seraient donc plus efficaces pour créer des interfaces utilisables, efficientes et non distrayantes qu'un atelier participatif collectif. En ce qui concerne les concepts individuels, ils ont été perçus comme aussi utilisables que le concept UCD. Néanmoins, l'utilisabilité objective mesurée était plus élevée, et la distraction visuelle inférieure, avec le concept UCD qu'avec les concepts PDInd. Il y a deux interprétations possibles à cette non-correspondance entre les aspects subjectifs et objectifs. L'utilisabilité perçue et l'utilisabilité réelle pourraient être totalement indépendantes. La conception participative individuelle résulterait en une augmentation de l'utilisabilité perçue, sans améliorer l'utilisabilité réelle. En ce sens, Tractinsky, Katz et Ikar (2000) ont proposé que l'utilisabilité réelle et perçue soient traitées séparément car elles évolueraient de façon indépendante. Deuxièmement, les conducteurs pourraient surestimer leur production. En effet, l'attrait pour le choix (Leotti, Iyengar, & Ochsner, 2010) et la prise de décision ont un impact sur l'expérience subjective, allant même jusqu'à une activation cérébrale des circuits associés à la motivation et à la récompense (Leotti & Delgado, 2011). Dans tous les cas, les ateliers de conception individuelle ont démontré des avantages subjectifs. Bien que les différences n'étaient pas significatives, après avoir testé les trois concepts, plus de la moitié des conducteurs ont classé leur concept en première position (52%), contre 33% pour le concept UCD, et 15% pour le concept PDWS. En ce qui concerne les mesures objectives et dans les conditions de cette étude, le fait que le concept UCD ait montré de meilleurs résultats indiquerait que les conducteurs auraient des méta-représentations incorrectes de ce qu'ils pourraient traiter de façon efficace et sécuritaire. Au contraire, les experts pourraient s'appuyer sur leurs connaissances et leur expertise pour concevoir des tableaux de bord efficaces et minimisant la distraction liée à leur usage. Ceci est conforme aux résultats de DeSmet et al. (2016) montrant que la conception participative peut être contre-productive en efficacité pour des applications médicales. En somme, les experts ont su concevoir des tableaux de bord plus sécuritaires et efficients que les conducteurs, et aussi (voire plus) utilisables et acceptables.

2.4.2. La qualité ergonomique des interfaces est-elle impactée de la même manière *selon la méthode participative mise en œuvre ?*

A nouveau, les mesures subjectives et objectives ont été impactées différemment entre les deux concepts participatifs.

Sur le plan subjectif, la différence entre les concepts résultant des deux méthodes participatives était très marquée. Les concepts individuels ont été perçus comme plus utilisables et acceptables que le concept PDWS. En outre, les conducteurs ont fortement préféré leur concept (plus de la moitié d'entre eux l'ont classé en premier), tandis que plus de la moitié des participants ont classé le concept PDWS en dernière position.

Sur le plan objectif, les écarts entre les deux concepts participatifs étaient réduits. Les différences semblaient isolées sur trois tâches, sans différence significative globale en termes d'efficience et de distraction visuelle (variables combinées sur toutes les tâches).

La première considération au regard de ces résultats est que l'utilisabilité, la distraction et l'acceptation ne sont pas affectées de la même manière entre les deux méthodes participatives mises en œuvre. L'utilisabilité perçue et l'acceptation étaient nettement meilleures pour les concepts PDInd que pour le concept PDWS. Cela suggère que certaines méthodes PD seraient plus efficaces que d'autres. Cela correspond aux résultats rapportés par DeSmet et al. (2016) qui ont mis en évidence des différences d'efficacité selon les méthodes participatives appliquées. Il est donc essentiel d'étudier la conception participative en considérant la variété des méthodes possibles. En outre, ces résultats ont démontré une utilité et une intention d'utilisation accrues pour les conceptions personnelles par rapport au concept collectif. Trois interprétations sont possibles. Tout d'abord, comme mentionné ci-dessus, le choix et la prise de décision pourrait avoir une influence sur l'expérience subjective. Deuxièmement, les sessions de conception individuelle permettraient d'éliciter les besoins individuels (Fan & Poole, 2006 ; Sleeswijk Visser et al., 2005), qui seraient spécifiques à chaque individu et non partagés collectivement. La troisième hypothèse serait que le groupe de quatre utilisateurs impliqués lors de l'atelier collectif n'aurait pas réussi à traduire les besoins des utilisateurs finaux (Mugge, Schoormans, & Schifferstein, 2009). Selon cette dernière hypothèse, les mécanismes de consensus et d'intelligence collective spécifiques aux ateliers en groupe (Sanoff, 2007) ne seraient pas aussi bénéfiques qu'attendu sur les résultats.

2.5. Limites et ouvertures

Plusieurs limites sont à prendre en compte. Tout d'abord les limites liées à l'objet d'étude sont présentées, puis les limites liées aux méthodologies employées, pour finir sur des recommandations pour de futures recherches.

2.5.1. *Limites liées à l'objet d'étude*

D'abord, plusieurs obstacles ont été rencontrés lors de la mise en place de la conception participative pour la conception d'IHM poids-lourd. En effet, la conception des IHM implique de nombreuses contraintes telles que des logiciels difficiles à utiliser, les interfaces ne sont pas de série et doivent couvrir toutes les configurations de véhicules, les aspects réglementaires doivent être pris en compte, des connaissances sont nécessaires sur les aspects techniques. Dans cette recherche, les conducteurs étaient représentatifs d'un sous-ensemble de conducteurs (identifié dans le cluster 1 du premier sous-projet), ils ont travaillé sur un sous-ensemble de fonctions (fonctions essentielles de conduite) et n'ont pas exploré tous les points abordés par les experts (e.g. profondeur des menus).

Deuxièmement, les trois concepts testés différaient en termes de niveau d'implication des utilisateurs pendant le processus de conception, mais également selon d'autres aspects. Les trois concepts ont été comparés afin d'évaluer indirectement la méthode de conception, mais il serait intéressant d'identifier et de spécifier les paramètres qui varient entre les différents concepts, tels que la densité de l'affichage qui peut affecter l'efficacité de la recherche visuelle (Moacdieh & Sarter, 2015), ou l'efficacité des représentations choisies pour chaque fonction. Il serait par exemple intéressant de sélectionner plusieurs critères permettant de caractériser une distance entre les concepts. Par exemple, cela permettrait d'estimer si le concept UCD avait un degré de différence plus élevé avec le concept PDWS qu'avec les concepts PDInd. En outre, cela permettrait de mettre en évidence les variables les plus impliquées dans les différences entre les concepts (e.g. densité visuelle, disposition, tailles, ou fonctions choisies). Pour cela, une analyse des correspondances multiples pourrait être réalisée.

2.5.2. Limites liées aux processus implémentés

D'autres méthodes auraient pu être étudiées. Spinuzzi (2005) a proposé trois critères pour évaluer les processus de conception participative impliquant des travailleurs industriels: la qualité de vie des travailleurs (i.e. améliorer la qualité de vie des travailleurs, en termes d'autonomisation organisationnelle et de facilité d'exécution de leur tâche), le développement collaboratif (i.e. les utilisateurs sont pleinement impliqués, avec la détermination d'une langage et des objectifs communs), et enfin un processus itératif (i.e. participation continue des travailleurs pendant plusieurs étapes assurant une réflexion soutenue). Pour transférer cette idée à notre cas d'étude, les critères seraient : une meilleure qualité des IHM, une implication active des conducteurs, et un processus itératif à travers les différentes étapes du processus. Les trois critères ont été respectés dans cette recherche. Cependant, il existe de nombreuses autres façons de collecter un résultat correspondant à une conception centrée sur l'utilisateur (e.g. avec d'autres ou plus d'experts, plus d'itérations, plus de conducteurs évaluant les concepts), ou pour obtenir un résultat participatif sur le même cas de conception (e.g. différents rôles pour les utilisateurs et les experts, d'autres activités de conception, un nombre plus élevé de conducteurs impliqués). Il serait intéressant de collecter des données sur d'autres processus UCD et PD afin de valider ces résultats.

De même, d'autres rôles auraient pu être testés concernant la conception participative. Dans ce projet, des rôles spécifiques ont été expérimentés, avec un design par les utilisateurs au sens strict. En effet, les conducteurs jouaient pleinement leur rôle de concepteurs, et les experts avaient un rôle de facilitateurs. Nous avons expérimenté ces rôles pour plusieurs raisons : (1) les progrès technologiques ont permis l'émergence de tels rôles, (2) cela faisait partie de l'aspect moral de la conception participative (donner du pouvoir aux utilisateurs), (3) pour ne pas entraver la liberté d'expression des utilisateurs par des aspects sociaux ou des contraintes techniques avancées par les experts, et (4) pour les perspectives que cela pouvait ouvrir sur la personnalisation des tableaux de bord. Certains des tableaux de bord participatifs n'auraient jamais été produits par des experts et ont entraîné une grande satisfaction du côté des conducteurs. Ces données sont donc une contribution intéressante pour les experts. Cependant, l'ISO 9241-210 (2010) suggère que « l'efficacité de la participation des utilisateurs augmente à mesure que l'interaction entre les développeurs et les utilisateurs augmente ». De plus, Ehn (1993) a proposé que les avantages de la conception participative reposeraient sur la rencontre entre les connaissances tacites des utilisateurs et les connaissances analytiques plus abstraites des experts. Dans cette recherche, cette combinaison des deux types de connaissances a peut-être été manquante. Une collaboration avec des rôles équivalents entre les experts et les utilisateurs permettrait de combiner les connaissances et les compétences des concepteurs (e.g. point de vue holistique, connaissance des coûts, des contraintes techniques, de l'image de marque, des facteurs humains et des recommandations ergonomiques) avec la connaissance des utilisateurs (i.e. expertise du contexte d'utilisation, expérience avec d'autres marques et dispositifs, certainement plus à l'aise avec les compromis, perspective individuelle).

2.5.3. Perspectives de recherche

Les effets à long-terme devraient être évalués. Clement et Van den Besselaar (1993) ont rapporté le manque de données sur les effets à long terme de la conception participative. Faute de temps, cet aspect n'a pas pu être abordé dans ce projet. Néanmoins, ces données sont essentielles pour évaluer les effets de l'implication de l'utilisateur au fil du temps, avec de potentielles adaptations comportementales. En outre, dans cette étude, le délai entre la conception individuelle et la phase d'évaluation des concepts était réduit. Bien que cela correspondrait à un contexte réel de personnalisation, et bien que cet effet ait été réduit par les temps de familiarisation avec les deux autres concepts, d'autres études pourraient augmenter ce délai. De plus, des études antérieures ont rapporté des évolutions d'utilisabilité au fil du temps (e.g. Guerreiro, Nicolau, Jorge, & Gonçalves, 2009 ; Sonderegger, Zbinden, Uebelbacher, & Sauer, 2012 ; Von Wilamowitz-Moellendorf, Hassenzahl, & Platz, 2006). Karapanos, Zimmerman, Forlizzi et Martens (2009) ont proposé un modèle de l'utilisation d'un produit au fil du temps composé de trois phases : l'orientation (première expérience de l'utilisateur avec le produit), l'incorporation (intégration du produit dans la vie quotidienne de l'utilisateur), et l'identification (produit fait partie de l'identité de soi de l'utilisateur). Il a suggéré que la première phase serait affectée par l'esthétique et la facilité d'apprentissage du produit, la deuxième phase par l'utilisabilité à long terme et l'utilité, et la dernière phase par des aspects sociaux et personnels. Une étude à long terme portant sur ces trois phases serait également un indicateur intéressant sur la durabilité des approches de conception.

Enfin, la conception participative individuelle ouvre des perspectives pour la personnalisation des tableaux de bord. Fan et Poole (2006) ont indiqué que l'un des moyens de tirer le meilleur parti des besoins individuels de l'utilisateur est de permettre à l'utilisateur de personnaliser explicitement le produit. En outre, Normark (2015) a proposé un équipement expérimental proche de celui utilisé dans cette étude afin d'étudier la personnalisation des interfaces voitures à l'aide d'un écran tactile. Il a reporté un effet positif sur l'expérience subjective des conducteurs. Les résultats de ce projet ont montré un fort niveau d'utilisabilité et d'acceptation pour les concepts individuels, corroborant cette idée. Cependant, contrairement à l'hypothèse suggérée par Marcus (2004), les concepts individuels n'ont pas permis une réalisation des tâches plus rapide et plus sécuritaire que pour le concept issu de la conception centrée sur l'utilisateur. De futures recherches pourraient explorer les effets des différents niveaux de personnalisation du tableau de bord sur les critères d'efficience et de distraction.

3. Conclusion

Les avantages de la conception participative rapportés dans d'autres domaines ont ouvert des perspectives d’optimisation de la qualité ergonomique des IHM poids-lourd. À l'aide d'un outil de prototypage tactile sur simulateur de conduite, trois concepts de tableaux de bord ont été générés. La conception centrée sur l'utilisateur correspondait à un niveau d’implication consultatif. Deux méthodes participatives ont été mises en œuvre : un atelier collectif et des sessions individuelles, correspondant à un niveau d’implication participatif. Les résultats ne permettent pas de démontrer qu’une conception participative a un impact significatif sur l’utilisabilité, la distraction et l’acceptation. Le concept issu de la conception centrée sur l'utilisateur s'est révélé plus efficace, plus sûr, et aussi – voire plus – utilisable et acceptable que les concepts participatifs. En outre, des différences ont été montrées entre les deux méthodes participatives mises en œuvre, appelant à une étude approfondie des méthodes participatives utilisées. Enfin, les résultats ont démontré l'importance de mesurer de façon conjointe les aspects subjectifs et objectifs, qui se sont révélés indépendants et complémentaires. A un niveau plus global, ces résultats questionnent la capacité des utilisateurs à décider pour eux-mêmes et invitent à étudier plus en détail les déterminants des avantages subjectifs de la conception participative. Par exemple, si les avantages reposaient principalement sur la possibilité de choisir et de prendre des décisions, proposer plusieurs concepts conçus par des experts suffirait à améliorer l'expérience des utilisateurs sans impacter les aspects objectifs.

References

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.

Bevan, N. (2001). International standards for HCI and usability. International journal of human-computer studies, 55(4), 533-552.

Bevan, N., Kirakowski, J., & Maisse, J. (1991, September). What is Usability? In Proceedings of the 4th International Conference on HCI. Elsiever.

Beyer, H., & Holtzblatt, K. (1999). Contextual design. Interactions, 6(1), 32-42.

Blomberg, J., Giacomi, J., Mosher, A., & Swenton-Wall, P. (1993). Ethnographic field methods and their relation to design. Participatory design: Principles and practices, 123-155.

Bossen, C., Dindler, C., & Iversen, O. S. (2010, November). User gains and PD aims: assessment from a participatory design project. In Proceedings of the 11th Biennial Participatory Design Conference (pp. 141-150). ACM.

Bossen, C., Dindler, C., & Iversen, O. S. (2016, August). Evaluation in participatory design: a literature survey. In Proceedings of the 14th Participatory Design Conference: Full papers -Volume 1 (pp. 151-160). ACM.

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.

Carmel, E., Whitaker, R. D., & George, J. F. (1993). PD and joint application design: a transatlantic comparison. Communications of the ACM, 36(6), 40-48.

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., & Olson, J. R. (1987). Mental models in human-computer interaction: Research issues about what the user of software knows. Committee on Human Factors, Commission on Behavioral and Social Sciences and Education, National Research Council.

Carroll, J. M., & Rosson, M. B. (2007). Participatory design in community informatics. Design studies, 28(3), 243-261.

Cavaye, A. L. (1995). User participation in system development revisited. Information & Management, 28(5), 311-323.

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.

Damodaran, L. (1996). User involvement in the systems design process-a practical guide for users. Behaviour & information technology, 15(6), 363-377.

DeSmet, A., Thompson, D., Baranowski, T., Palmeira, A., Verloigne, M., & De Bourdeaudhuij, I. (2016). Is participatory design associated with the effectiveness of serious digital games for healthy lifestyle promotion? A meta-analysis. Journal of medical Internet research, 18(4).

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.

Ehn, P. (1993). Scandinavian design: On participation and skill. Participatory design: Principles and practices, 41-77.

Engström, J., Arfwidsson, J., Amditis, A., Andreone, L., Bengler, K., Cacciabue, P. C., Janssen, W., Kußmann, H., & Nathan, F. (2006). Towards the automotive HMI of the future: mid-term results of the AIDE project. In Advanced Microsystems for Automotive Applications 2006 (pp. 379-405). Springer Berlin Heidelberg.

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.

Floyd, C., Mehl, W. M., Reisin, F. M., Schmidt, G., & Wolf, G. (1989). Out of Scandinavia: Alternative approaches to software design and system development. Human-Computer Interaction, 4(4), 253-350.

Gkouskos, D., Normark, C. J., & Lundgren, S. (2014). What drivers really want: Investigating dimensions in automobile user needs. International Journal of Design, 8(1).

Guerreiro, T., Nicolau, H., Jorge, J., & Gonçalves, D. (2009, October). NavTap: a long term study with excluded blind users. In Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility (pp. 99-106). ACM.

Haines, H., Wilson, J. R., Vink, P., & Koningsveld, E. (2002). Validating a framework for participatory ergonomics (the PEF). Ergonomics, 45(4), 309-327.

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.

Herstatt, C., & Von Hippel, E. (1992). From experience: Developing new product concepts via the lead user method: A case study in a “low-tech” field. Journal of product innovation management, 9(3), 213-221.

Hesse, T., Engström, J., Johansson, E., Varalda, G., Brockmann, M., Rambaldini, A., Fricke, N., Flemish, F., Köster, F., & Kanstrup, L. (2011, July). Towards user-centred development of integrated information, warning, and intervention strategies for multiple ADAS in the EU project interactive. In International Conference on Universal Access in Human-Computer Interaction (pp. 280-289). Springer, Berlin, Heidelberg.

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 (2010). ISO 9241-210 - Ergonomics of human-system interaction – Human-centered design for interactive systems. International Organization for Standardization.

Ives, B., & Olson, M. (1981). User Involvement in Information Systems: A critical review of the empirical literature. New York: New York University.

Karapanos, E., Zimmerman, J., Forlizzi, J., & Martens, J. B. (2009, April). User experience over time: an initial framework. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 729-738). ACM.

Khaled, R., & Vasalou, A. (2014). Bridging serious games and participatory design. International Journal of Child-Computer Interaction, 2(2), 93-100.

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.

Lee, J.H. (2008). User-Designer Collaboration during the Early Stage of the Product Development Process (Doctoral dissertation, Queensland University of Technology). Retrieved from https://eprints.qut.edu.au/26372/1/Jong_Ho_Lee_Thesis.pdf.

Leonard, D., & Rayport, J. F. (1997). Spark innovation through empathic design. Harvard business review, 75, 102-115.

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.

Maguire, M. (2001). Methods to support human-centred design. International journal of human-computer studies, 55(4), 587-634.

Marberger, C., Dangelmaier, M., Widlroither, H., & Bekiaris, E. (2004). User centred HMI development in the AWAKE-project. In Systems, Man and Cybernetics, 2004 IEEE International Conference on (Vol. 1, pp. 170-175). IEEE.

Marcus, A. (2004). The next revolution: vehicle user interfaces. Interactions, 11(1), 40-47.

Moacdieh, N., & Sarter, N. (2015). Display clutter: A review of definitions and measurement techniques. Human factors, 57(1), 61-100.

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.

Nielsen, J. (2008). Bridging the designer-user gap. Nielsen Norman Group. Retrieved from https://www.nngroup.com/articles/bridging-the-designer-user-gap/

Nonaka, L., Takeuchi, H., & Umemoto, K. (1996). A theory of organizational knowledge creation. International Journal of Technology Management, 11(7-8), 833-845.

Normark, C. J. (2015). Design and evaluation of a touch-based personalizable in-vehicle user interface. International Journal of Human-Computer Interaction, 31(11), 731-745.

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.

Pilemalm, S., & Timpka, T. (2008). Third generation participatory design in health informatics—making user participation applicable to large-scale information system projects. Journal of biomedical informatics, 41(2), 327-339.

Rogers, Y., Sharp, H., & Preece, J. (2011). Interaction design: beyond human-computer interaction. John Wiley & Sons.

Ross, T., Midtland, K., Fuchs, M., Pauzié, A., Engert, A., Duncan, B., Vaughan, G., Vernet, M., Peters, H., Burnett, G., & 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.

Scariot, C. A., Heemann, A., & Padovani, S. (2012). Understanding the collaborative-participatory design. Work, 41(Supplement 1), 2701-2705.

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.

Sonderegger, A., Zbinden, G., Uebelbacher, A., & Sauer, J. (2012). The influence of product aesthetics and usability over the course of time: a longitudinal field experiment. Ergonomics, 55(7), 713-730.

Tractinsky, N., Katz, A. S., & Ikar, D. (2000). What is beautiful is usable. Interacting with computers, 13(2), 127-145.

Von Wilamowitz-Moellendorff, M., Hassenzahl, M., & Platz, A. (2006). Dynamics of user experience: How the perceived quality of mobile phones changes over time. In User Experience - Towards a unified view, Workshop at the 4th Nordic Conference on Human-Computer Interaction (pp. 74-78).

Weinschenk, S. (2011). 100 things every designer needs to know about people. Pearson Education.

Appendices

Appendix 1: Widgets available for each function

Function category	Widget
Elements	SeparatorHorizontalLine SeparatorVerticalLine
ADAS	ADASAccFront ADASAccFrontCombo ADASAccSide ADASAccSideCombo ADASPicto ADASTargetSpeed ADASText
AdBlue	AdBlueCircularHorizontalBargraph AdBlueCircularHorizontalPointer AdBlueLinearHorizontalBargraph AdBlueLinearHorizontalPointer AdBlueLinearVerticalBargraph AdBlueLinearVerticalPointer AdBlueSemiCircularHorizontalBargraph AdBlueSemiCircularHorizontalPointer AdBlueSemiCircularLeftBargraph AdBlueSemiCircularLeftPointer AdBlueSemiCircularRightBargraph AdBlueSemiCircularRightPointer AdBlueText
AirPressure	AirPressureCircularHorizontalBargraph AirPressureCircularHorizontalPointer AirPressureLinearHorizontalBargraph AirPressureLinearHorizontalPointer AirPressureLinearVerticalBargraph AirPressureLinearVerticalPointer AirPressureSemiCircularHorizontalBargraph AirPressureSemiCircularHorizontalPointer AirPressureSemiCircularLeftBargraph AirPressureSemiCircularLeftPointer AirPressureSemiCircularRightBargraph AirPressureSemiCircularRightPointer AirPressureText
Battery	BatteryCircularHorizontalBargraph BatteryCircularHorizontalPointer BatteryLinearHorizontalBargraph BatteryLinearHorizontalPointer BatteryLinearVerticalBargraph BatteryLinearVerticalPointer BatterySemiCircularHorizontalBargraph BatterySemiCircularHorizontalPointer BatterySemiCircularLeftBargraph BatterySemiCircularLeftPointer BatterySemiCircularRightBargraph BatterySemiCircularRightPointer BatteryText BatteryHoursText
Comfort	ComfortAlarmClockText ComfortCompassText ComfortDateText ComfortExternalTemperatureText ComfortHourClock ComfortHourText ComfortTimerText
DPF	DPFCircularHorizontalBargraph DPFCircularHorizontalPointer DPFLinearHorizontalBargraph DPFLinearHorizontalPointer DPFLinearVerticalBargraph DPFLinearVerticalPointer DPFSemiCircularHorizontalBargraph DPFSemiCircularHorizontalPointer

Function category	Widget
	DPFSemiCircularLeftBargraph DPFSemiCircularLeftPointer DPFSemiCircularRightBargraph DPFSemiCircularRightPointer DPFText
EngineTemp	EngineTempCircularHorizontalBargraph EngineTempCircularHorizontalPointer EngineTempLinearHorizontalBargraph EngineTempLinearHorizontalPointer EngineTempLinearVerticalBargraph EngineTempLinearVerticalPointer EngineTempSemiCircularHorizontalBargraph EngineTempSemiCircularHorizontalPointer EngineTempSemiCircularLeftBargraph EngineTempSemiCircularLeftPointer EngineTempSemiCircularRightBargraph EngineTempSemiCircularRightPointer EngineTempTelltale EngineTempText
Fuel	FuelCircularHorizontalBargraph FuelCircularHorizontalPointer FuelLinearHorizontalBargraph FuelLinearHorizontalPointer FuelLinearVerticalBargraph FuelLinearVerticalPointer FuelSemiCircularHorizontalBargraph FuelSemiCircularHorizontalPointer FuelSemiCircularLeftBargraph FuelSemiCircularLeftPointer FuelSemiCircularRightBargraph FuelSemiCircularRightPointer FuelText
Gearbox	GearboxGear GearboxGearMode GearboxGearPosition GearboxGearPositionMode GearboxPattern GearboxScale
Oil	OilCircularHorizontalBargraph OilCircularHorizontalPointer OilLinearHorizontalBargraph OilLinearHorizontalPointer OilLinearVerticalBargraph OilLinearVerticalPointer OilSemiCircularHorizontalBargraph OilSemiCircularHorizontalPointer OilSemiCircularLeftBargraph OilSemiCircularLeftPointer OilSemiCircularRightBargraph OilSemiCircularRightPointer OilText
Radio	RadioFrequencyText RadioModeText RadioPresetText RadioStationText RadioVolumeText
Retarder	RetarderLevel RetarderPicto RetarderPictoLevel
Speed	SpeedCircularHorizontalBargraph SpeedCircularHorizontalPointer SpeedDigital SpeedLinearHorizontalBargraph SpeedLinearHorizontalPointer SpeedLinearVerticalBargraph SpeedLinearVerticalPointer SpeedSemiCircularHorizontalBargraph SpeedSemiCircularHorizontalPointer SpeedSemiCircularLeftBargraph SpeedSemiCircularLeftPointer SpeedSemiCircularRightBargraph

Function category	Widget
	SpeedSemiCircularRightPointer
Tacho	TachoAvailabilityTimeText TachoBreakTimeText TachoDailyDrivingTime TachoDrivingTimeText TachoWeek1TimeOdometer TachoWeek2TimeOdometer TachoWorkingTimeText
Tachometer	TachometerCircularHorizontalBargraph TachometerCircularHorizontalPointer TachometerDigital TachometerLinearHorizontalBargraph TachometerLinearHorizontalPointer TachometerLinearVerticalBargraph TachometerLinearVerticalPointer TachometerSemiCircularHorizontalBargraph TachometerSemiCircularHorizontalPointer TachometerSemiCircularLeftBargraph TachometerSemiCircularLeftPointer TachometerSemiCircularRightBargraph TachometerSemiCircularRightPointer
TripComputer	TripComputerAdBlueConsumptionAverageText TripComputerAdBlueConsumptionVolumeText TripComputerAverageSpeedText TripComputerFuelAverageConsumptionText TripComputerFuelConsumptionVolumeText TripComputerFuelEndurenceText TripComputerIdleEngineHoursText TripComputerOdometerText TripComputerTotalEngineHoursText TripComputerTripOdometerText