DOES ELECTRIC-MOBILITY SOUND FUTURISTIC? CONCEPTUALIZATION DESIGN STRATEGIES FOR THE AUDITORY VEHICLE ALERTING SYSTEM (AVAS)

Rosana Sanz-Segura[1], Eduardo Manchado-Pérez[2]

[1]Universidad de Zaragoza. Escuela de Ingeniería y Arquitectura (EINA). Departamento de Ingeniería de Diseño y Fabricación. Calle María de Luna, 3, 50018 Zaragoza. Investigadora del Critical Alarms Lab (CAL) TUDelft (Países Bajos). Teléfono: 629 99 39 74. rsanz@unizar.es

[2]Universidad de Zaragoza. Escuela de Ingeniería y Arquitectura (EINA). Departamento de Ingeniería de Diseño y Fabricación. Calle María de Luna, 3, 50018 Zaragoza.

Received: 15/Jul/20 – Reviewing: 15/Jul/20 -- Accepted: 16/Sep/20 - DOI: http://dx.doi.org/10.6036/9857

1.- INTRODUCTION

"I think something that would be super cool would be to (…) create a China design and engineering center to actually design an original car in China for worldwide consumption." This announcement, made by Tesla CEO Elon Musk -after closing 2019 with an increase in the forecast sale of its electric vehicles and confirming a new engineering and design center in the giant Chinese market- reveals the challenging opportunity for designers in the conceptualization of new models of electric vehicles.

Electric cars imply some new design tasks. From 1st September 2019, every new electric vehicle (EV) and hybrid vehicle (HEV) model must be equipped with the Acoustic Vehicle Alerting System (AVAS) to comply with US regulations [1]–[2]. This regulation entered into the European market last July 2019 (UN Regulation No. 138 - Rev.1 - Quiet Road Transport Vehicles (QRTV). The United Nations Economic Commission for Europe (UN ECE) will extend this regulation from 2021 to all commercialized models [3]. AVAS is the additional warning system that EVs and HEVs will incorporate to be heard at low speeds. This regulation is motivated specially by the need of inattentive pedestrians, visually impaired people and drivers on a lower speed range (e.g., cyclists, bikers…) of an acoustic warning to detect the presence of these "quiet" vehicles.

Aditionally, sound design conceptualization of electric mobility goes beyond AVAS. It means a challenge not only in terms of complying safety regulations; but also, an opportunity to fit brand identity requirements; to define the future sensory driving experience; and the responsibility of creating new urban sound environments. Some manufacturers such as Tesla have already equipped their models with AVAS; and also have begun to explore the possibilities of product sound design applied to electric mobility on a wider approach.

This article presents the role of sound design in the conceptualization of new EVs and HEVs according to the recent AVAS regulation, and further. The contribution is structured in three parts: part 1) highlights the users' needs related to e-mobility design and the role of sound design to improve road safety and driving experience; part 2) introduces different strategies for AVAS sound design conceptualization until the date; part 3) some key points are presented to designers in order to guide the sound conceptualization as part of the design process, and future lines of research are considered.

2.- USERS' NEEDS IN ELECTRIC-MOBILITY DESIGN

User-centred design approaches are well known in the automotive sector [4]. The success of a product in today's market depends on how the design solution satisfies user needs. According to authors, some correspond to functional and physical needs, while others are emotional and experiential needs. Some needs are intrinsic to any human life, while others are consequence of social or cultural environments and/or technology evolution.

When it comes to cars, different stakeholders are identified: drivers; passengers; pedestrians; neighbours; institutions; policy makers; manufacturers. Driver needs concern control, security, and emotional driving experience. Pedestrians, other drivers and institutions needs are related to security issues, while passengers and neighbours' concerns are mostly related to avoid disturbing noises caused by cars' performance.

Policy makers and car manufacturers care about all these different user´s needs. The strategies followed by manufacturers differ but usually focus on road safety and driver emotional experience. Even before cars began to be electric, they turned to be almost noiseless. Consequently, some users' needs that were incidentally satisfied by the noise of internal combustion engines (ICE), required the development of new functions. Thus, the recognition by pedestrians of a car approaching was enhanced by the approaching Vehicle Sound for Pedestrian (VSP), and the driver´s perception of the vehicle performance was enhanced by the Gear Shift Indicator (GSI). Current revolutionary advances imply the need to comply with legal safety requirements but also to provide a new sound driving experience.

2.1.- SOUND DESIGN FOR ROAD USERS' SAFETY. THE ACOUSTIC VEHICLE ALERTING SYSTEM (AVAS).

Some accidents occur with higher incidence rates for EVs/HEVs than ICE vehicles [5]. Vulnerable road users as the visually impaired are not able to detect these silent vehicles when they approach. Blind federations dismiss the idea of ring tones and demand a sound that "should be recognizable and non-intrusive, and relatively quiet — it shouldn't mask the other important environmental sounds we encounter" and suggest that "vehicles must make a sound at all times, even when they are idling," [5]. "Quiet" vehicles" are also a risk for the "technological zombies", those people distracted by wearing headphones or using their smartphones. The addition of artificial alert sounds according to the AVAS improves vehicles movement detectability [5,6]. Today, AVAS systems are formulated by two major regulations: United Nations Economic Commission for Europe (UN ECE, Regulation 138) and the Federal Motor Vehicle Safety Standards (FMVSS, Regulation 141) for the United States (US) [2,3,4].

Fig 1. AVAS improves vehicles movement detectability and prevents road users.

The existing regulation lists sounds that are prohibited or should be avoided. But manufacturers can still define the vehicles' sounds to a large extent in order to establish innovative sounds. Currently, the available information from the UN ECE Regulation is that: 1) the AVAS shall automatically generate a sound in the minimum range of vehicle speed from start up to approximately 20 km/h and during reversing. Where the vehicle is equipped with an ICE that is in operation within the vehicle speed range defined above, the AVAS shall not generate a sound. For vehicles having a reversing sound warning device, it is not necessary for the AVAS to generate a sound whilst reversing; 2) the AVAS shall be fitted with a switch which is easily accessible by the vehicle driver in order to allow engaging and disengaging (pause switch). Upon restarting the vehicle, AVAS shall default to the switched-on position; 3) the AVAS sound level may be attenuated during periods of vehicle operation; 4) the sound to be generated by the AVAS shall be a continuous sound that provides information to the pedestrians and other road users of a vehicle in operation. The sound should be easily indicative of vehicle behaviour (for example, through the automatic variation of sound level or characteristics in synchronization with vehicle speed); and should sound similar to the sound of a vehicle of the same category equipped with an ICE; 5) the sound level generated by the AVAS shall not exceed the approximate sound level of a vehicle of the M1 category equipped with an ICE and operating under the same conditions. To extend, see an overview of the legal requirements in the EU and US.

2.2.- SOUND DESIGN FOR DRIVING EXPERIENCE OF BRAND IDENTITY.

The aim of any brand is to get a singular, enduring, and memorable identity in the form of semantic content that positions a reference point when people think about their product. In addition to safety requirements, sound design is equally critical to the success of the brand experience of any product/service/environment. A sonic trademark provides to the sound brand (through a piece of audio) what a visual trademark brings to the visual identity [7].

In the age of conversational assistants and sonic interactions, digital sounds such as ringtones, audio logos, or jingles are familiar. In the automotive industry, functionality and appeal of sounds are equally relevant. Companies such as Harley Davidson rely on the recognition of its brand in the characteristic sound of its engines [7]. Similarly, Volkswagen embodied the sound of a door slamming on their tv commercials as a referent value of its brand signature, providing the audience a sense of the toughness of their vehicles through sound design.

3.- DESIGN CONCEPTUALIZATION STRATEGIES FOR AN AVAS IN TODAY'S MARKET

EVs and HEVs manufacturers have already followed different sound conceptualization strategies for their AVAS. Having different strategies, designers tried usually to assess the effects of different sound solutions for AVAS in terms of (un)pleasantness, acceptance, or emotional response, among others [8]. Following, three main categories are presented according to the semantic referent used by brands for AVAS sound until the date.

i) Combustion engine sound. The most conservative design solutions for AVAS opt for simulating the conventional sound of an internal combustion engine. The use of an everyday sound which already has an extended meaning for pedestrians is the strategy promoted by visually impaired organisations in order to trust in their “sound memories” of traffic environments (e.g., hum, horn, whistle or engines)

ii) Electric engine sound. The design conceptualization of a “natural” operating sound of an EV is the most common strategy followed by brands until the date. This kind of AVAS solution aims to enhance the hearing sensation of an electric driving experience without the awareness of additional synthetic sounds. These brands present a futuristic-oriented soundscape that reminds the orchestral sound of science-fiction movies, but also explore how sounds may suggest identity values such as movement, power or energy.

iii) Miscellanea (not-an-engine) sound. More innovative strategies consider prospective alternatives to the engine-like sound to address the driving experience. For instance, Ayax (working for Toyota) proposes a new sound concept that provides a relaxing white noise supposed to stimulate the growth of plants, as an additional effort to revert the environmental impact of the car performance and to provide a friendlier soundscape for pedestrians, neighbourhoods and ecosystems.

AVAS solutions in today’s market evidence, more or less indiscriminately, sound design quality standards from acoustic literature as well as the use of “semantic association” as a method for the conceptualization stage. Thus, brand designers, marketers and engineers define internally their “semantic construct” according to their own brand values. Nevertheless, as we introduced above, conceptualization of sound for electric mobility is by far an unexplored ground. Consequently, the following section presents a more integrated design approach that covers academic and sound studies research.

4.- DESIGN GUIDELINES FOR AVAS CONCEPTUALIZATION

To establish an integrated brand strategy for both interior and exterior sound design of EVs and HEVs vehicles is an unprecedented challenge. Furthermore, the amount of sounds that can be potentially used as auditory messages for an AVAS is enormous, due to today´s ease of recording, editing and synthesizing sounds, as well as to the large storage capacity of current auditory systems [12]. The success and acceptance of new proposals will be conditioned not only by functional requirements but also by aesthetic, meaningful and emotional goals]. Besides, sound as a carrier of meaning has been relegated during the conceptualization stage in favour of visual mapping, and academia and professionals lack sound design references to guide the design process [34]–[35]. Consequently, designers seek guidelines for the conceptualization of sound solutions that meet the demands of the market in terms of safety and driving experience.

In order to comply with legal requirements and find the appropriate balance between pedestrians’ safety, environmental noise, and the subjective acoustic feedback, the design strategy must consider the entire sound ecology of the AVAS. Thus, current sound design solutions must be enriched with previous sound studies and semiotics approaches (i.e., how meaning is communicated) [9,10]. This is a combination of theory of communication principles with available sound design standards [11]–[12] provides designers a frame to guide the design of the AVAS solution. Following this approach, Figure 2 shows the three stages to address during the AVAS sound design and conceptualization process.

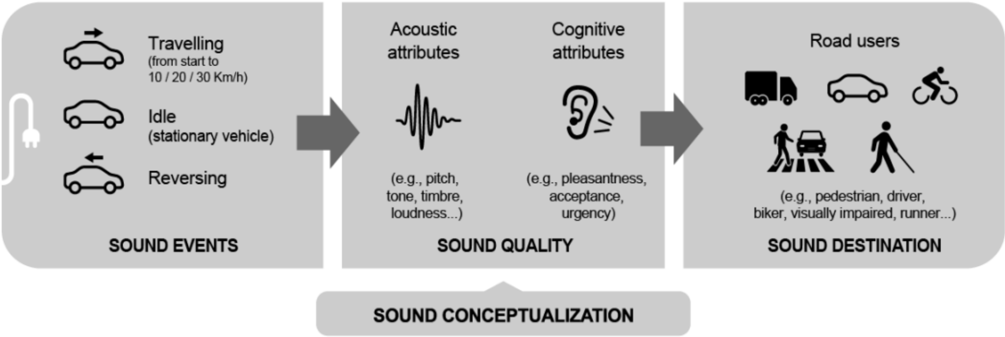

Fig 2. Sound design conceptualization for AVAS.

Hence, the design team must be aware of what information the AVAS should convey (i.e., SOUND EVENTS) in order to comply with legal requirements. According to this, the AVAS must communicate the vehicle driving condition and, in particular, further information about at least three critical events: a) travelling; b) idle; and c) reversing [8]. Then, the auditory message is defined during the design conceptualization stage in terms of SOUND QUALITY. Sound quality is a perceptual reaction and refers to the adequacy of the sound from a product to the related event that describes. The AVAS must be defined according to the totality of the sound's auditory characteristics: i) physical and acoustic parameters (e.g., pitch, tone, timbre, range of frequencies, loudness); and ii) cognitive attributes associated to it, with reference to the perceptual and emotional situation of the road user (i.e., SOUND DESTINATION). Ecological relevance must be considered by designers in order to understand the variety of scenarios, noise background and the most vulnerable road users (see Figure 1).

Even considering the entire ecology, designers' field of action is mainly focused on the sound quality stage. Sound quality must be conceptualized in order to create a semantic link between the sound events that refers to and the sound destination. Thus, different strategies of mapping the information to the auditory messages can be distinguished [7]. Depending on how literal is the relationship between the sound and the event we can find i) auditory icons; and ii) abstract sounds. Auditory icons are everyday sounds that refer to real events through meaningful relationships. (e.g., the emulating sound of the starting engine and ignition of an ICE car). These iconic sounds are intuitive, easy to learn, and a promising design choice because of the challenging use of symbols and metaphors in a sophisticated way. The sound of the mechanic turn signal relay has been replaced in cars with an electronic control by a synthesis sound based on that. Abstract sounds do not refer to any existing event through their acoustic structure (i.e., there is no relationship between the sound and its meaning). Most car feedback sounds are abstract sounds, due to their amenability to convey urgency patterns. The aim is not so keen to describe the event itself, but its criticality. (i.e. the same sound refers to different events, such as the 'beep' associated with seat belt reminders or the low pressure on a wheel, but different sounds are used to express the range of criticality of that event) [7].

Previous contributions in alarm and sound design studies can help designers to better understand the value of acoustic parameters and their influence on perceptual and cognitive aspects (e.g., learnability, localizability, masking) of these kinds of auditory messages. Table 1 is adapted from [7]-[12] to the field of EVs sound design and shows the scope of classes of sounds, as a consensus and extended classification, as well as their main acoustic and cognitive attributes to consider by designers. Acoustic and physical properties of the AVAS device are mainly relevant in order to comply with legal requirements related to road safety. On the other hand, cognitive attributes of the AVAS must be congruent with the sound quality of the interior sound and the sonic identity of the car manufacturer in terms of driving experience.

Classes of sounds			Acoustic aspects	Cognitive aspects
Abstract sounds	Non-verbal sounds	Modern abstract e.g. electronic synthesis sounds: 'bells', 'pings' (seat belt alarm, proximity sensor).	Dry, disruptive, heard in noise environments. Very often structured as intermittent percussive rhythm. Distinguishable pitch and temporal structure. Very similar among them. Indirect mapping. Some are amenable to urgency patterns. Usually one tone or a sequence of tones (earcons).	Sound 'working status' and/or 'alarm-like' Difficult to learn and distinguish. Trained users can learn, through use, information on vehicle performance status. Perceptual fatigue. Usually refer to the event criticality rather than to the event itself.
Auditory icons	Non-verbal sounds	Auditory icon e.g. electronic sound to indicate that warning light system is on	Masked by environmental sounds. Everyday sounds. Easy for mapping information (i.e. symbolic, nomic and metaphorical). High variation in acoustic structure. Complex spectral-temporal structure. Urgency patterns through variations in psychoacoustical parameters (timbre, pitch, rhythm, loudness and duration). Some are musical motives and melodies.	Not sound 'alarm-like' Music perception issues. Usually pleasant sounds. Easy to learn the meaning conveyed. Usually meaning is related to the sound event. Dependent on user preferences. Conceptual mapping issues.
	Verbal sounds	Speech Spearcons (digitally modified). e.g. navigator system indications, conversational interfaces, speech-based systems.	Some messages can be difficult to tailor to certain environments. Tonal and voice characteristics are to be considered. High amount of information to be stored and processed.	Intuitive and direct (no ambiguous). Context and language-dependent (culture, situation location). Non-global applications. Sometimes low compliance rate. Usually easy to understand but can interfere with passenger's conversation.

Table 1. Classes of sounds for the field of electric sound design. Adapted from [7]-[12]

Table 1 shows the three categories of auditory messages (i.e., classes of sounds) that can be distinguished: abstract sounds, auditory icons and speech sounds. The sound of the traditional ICE vehicles has become an auditory icon as part of our life sound experience. Hence, although its use could be considered a safe bet, reliable testing on EVs and HEVs has not yet been carried out in real environments. Furthermore, trying to replicate the sound of an ICE is not justified in terms of noise pollution; the sound of an ICE is outside the frequency range perceivable by people with hearing impairments; and the development options are limited to the already-known sounds. In fact, all current ICEs sound very similar whether they have a smaller or larger engine but further conceptualization solutions, beyond ICE sound replications, might sound diverse in the future. As an alternative, auditory icons inspired in the imaginary of sci-fi movies are being tested to verify if those are easier to learn. Meanwhile, some manufacturers collaborate with music composers to generate radically new, harmonic, music-like sounds to be implemented in cars performance. In addition to this, the latest technology advancements (e.g., sensors, wireless and digital computing) provide the resources to implement alternative sensory modalities (visual, auditory and/or tactile) to in-vehicle information systems in order to boost broader driving experiences and because of the high risk of driver distraction (e.g., sensors are used to link smart devices and emit different stimuli according to the position of approaching vehicles).

4.- DISCUSSION

Simulating the conventional sound of ICEs for EVs and HEVs can be the current option but not the best one considering the wide range of options available, both in terms of safety and brand experience. The potential role of digital and musical technology in a technical product offers industrial designers and vehicle engineers the freedom to provide different sound solutions for AVAS but, how will these technical sounds get into the subconscious of users to ensure a new safety road soundscape? In this regard, sound perception implies the consideration of specific circumstances, as the need for the receiver to correctly perceive the origin of sound: in adults, auditive scope is a permanent 360º (differing from visual). Thus, the physics of sound have also to be considered. For example, a bike driver detects a car approaching from the rear due to the progression of the sound of its engine, but it is also well-known how difficult it is for drivers to identify the position of an ambulance approaching when listening only to their distinctive sound, until visually locating its blinking lights. Sound is fundamental for perceiving primary information but might be not enough under certain context-related conditions.

Thus, the challenge for designers is taking full advantage of new-generation modern abstract and auditory icons developed from an integral sound design approach. That is, defining new meaningful stimuli, considering all stakeholders present in the ecology system, and the required means to ease their learnability, localizability, masking and the urgency patterns that a warning conveys (e.g., the EV is accelerating). To fully develop its potential, these design proposals need to explore beyond the mere replication of previously existing sounds.

Policy makers should establish future regulations to be not too-restrictive as to avoid the research, development, and implementation of alternative solutions but also all-purpose oriented to ensure users' road safety, functional driving needs and brand experience. On the other hand, car manufacturers will also be interested in the opportunity of brand characterization that sound design offers, as a relevant factor to impulse research, development and testing of alternative solutions. Forwards, future research lines will be devoted to assess the acceptance, reliability and detection of implemented AVAS solutions in real environments.

5.- CONCLUSIONS

This contribution reveals the conceptualization and implementation of the AVAS as a novelty challenge either to designers, manufacturers, institutions and policy makers. The addition of a warning sound should not contradict the anti-pollution and pro-sustainability movements that advocate a reduction in (noise) pollution in cities. Sustainability-oriented measures defend green alternatives such as bicycles, and electrichybrid or plug-in vehicles. However, a common aspect in all of them is that they hardly generate mechanical noises like those made by traditional ICE vehicles. The lack of noise makes it difficult to perceive the presence of a vehicle around, putting at risk the safety of pedestrians. In this regard, the visually impaired community and other vulnerable road users demand for inclusive policies that guarantee pedestrian safety. On the other hand, car manufacturers search for innovative design solutions that encourage the driving experience through a sonic brand identity. Therefore, the entire complexity of the new auditory system must be considered in order to produce a safe and pleasant urban soundscape.

Designers are responsible for replacing silence with sound due to functional but also aesthetic and emotional requirements. Hence, the AVAS solution development implies to carry out a conceptual and practical study of an unprecedented milestone that lacks previous references to guide the sound design process. In this regard, we advocate the need of considering auditory messages on the same level of other physical attributes of a product in order to have an entire aesthetic and unified user experience of the design solution. Definitely, this contribution presents the key points to consider during the early phases of the sound design process and offers a discussion in terms of the future soundscape of electric mobility.

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