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High visibility or quiet operation?: A statistical inference model of the wiper operation quality by the dual-code theory

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ABSTRACT

The motor industry has assured drivers that it will continually provide quality vehicles without compromising safety and comfort. In this sense, the quality of a product always needs to be determined by what the customer actually perceives, which has not been the case in the domain of wiper operation quality.

To maintain a quality prediction model for wiper operation, this article develops a multi-modal inference model considering both the visible quality (VQ) and acoustic and vibration quality (AVQ). Based on the cognitive multimodal information processing theory, the model combines the two kinds of perceived information from various wiper operating conditions, i.e., the level of visibility obtained by wiper operations, and noises or shudders during operation.

The regression model with regard to the customer's perceived quality was validated empirically, and an interesting gender effect was identified in the perception of wiper quality. Also, in place of the conventional quality evaluation method (e.g., checklists or jury charts), we suggest our model of the multimodal information processing theory not only to predict the perceived wiper operation quality (visibility and quietness), but also to apply it to other related fields in product quality measurement.

Relevance to industry: This study proposes a multi-modal quality index model -visibility and quietness- in assessing wiper operation. Our model can be used in place of the conventional quality evaluation method (e.g., checklists or jury charts) in both the motor industry and other related fields in product quality measurement.

1. Introduction

Quality can be defined in many ways. The Malcolm Baldrige National Quality Award (NIST, 2013) defines that quality is measured by meeting customer expectations. Crosby (1979, 1985) also defined quality as meeting users' requirements, at which point the cost of quality is justified. Practically, Deming (1986) claimed that quality is a triangle involving the interaction of the product and the customer, the way he or she uses the product, and how to train the customer. Furthermore, addressing a variety of user requirements, Mizuno (1988) distinguishes between exciting and required quality. Required quality is the set of standard characteristics that allows one to compete in the market, whereas exciting quality is the set of characteristics that differentiates the product from its competitors and forms a market niche.

There are two differing views for the overall quality of a product. First is the view of the manufacturer, which is primarily concerned with the design, engineering, and manufacturing processes involved in fabricating the product from the components. Here product quality is measured by the degree of conformance to predetermined specifications and standards. Early work on quality thus focused on creating standards that the collection of features and characteristics of a product contribute to its ability to meet the given required quality. Second is the view of the consumer or the actual user of the product, for which there is in need of forming exciting qualities. For most customers, a high-quality product is the one that satisfies their preferences and expectations. This consideration can include a number of characteristics of product quality evaluation, some of which contribute little or nothing to the functionality of the product, but are significant in providing

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customer satisfaction. Numerous studies on industrial design and industrial ergonomics (e.g., Chuang et al., 2001; Poirson et al., 2010; Luo et al., 2012) have thus continuously focused on reducing this wide gap by developing more thorough design guidelines or evaluative measures considering perceived quality from the user's perspective.

These two rather different perspectives on quality can also be applied to vehicle wiper operations, which are the main concern of this article. In particular, manufacturer perspectives have long dominated over the quality from a user's perspective. That is, though the functionality, efficiency, materials, and effective mechanical design of wiper operation have evolved constantly, it is still uncertain how to include the user's perception of the wiper operation quality into the design of the total wiper quality. In particular, the conventional high visibility characteristic of wiper operation has accordingly become no more exciting quality, and improving acoustic comfort in vehicle designs has been an active research area in the ergonomics research community (e.g., Hoshino et al., 1995; Montignies et al., 2010; Poirson et al., 2010; Walker et al., 2006; Wang and Wang, 2012).

Advancing from the basic functionalities of the wiper operation, modern vehicle design asks for quieter wipers, and this user requirement has also been one of the main customer complaints with regard to total vehicle quality. In this respect, improving windshield wiper quality (i.e., not only how long the blade lasts, but also how well it works) has been a key to ensuring customer satisfaction, and further dictates user experiences for better driving conditions (Bakar et al., 2009; Cerrato Jay, 2007; Fagervall and Nyman, 2000).

A large research effort also related to evaluate the acoustic quality of vehicle noises (Bodden et al., 1998; Fastl, 1997; Nor et al., 2008; Schneider and Wilhelm, 1995; Wang et al., 2007; Zwicker and Fastl, 1990), but many psychoacoustic metrics (such as loudness, sharpness, tonality, roughness, fluctuation strength, pleasantness, etc.) that can account for the quantitative relation between acoustic stimuli and human sensations have been unsuccessful at evaluating wiper operation noises (Bakar et al., 2009; Cerrato Jay, 2009. Hoshino et al., 1995; Montignies et al., 2010; Poirson et al., 2010; Walker et al., 2006; Wang and Wang, 2012). This difficulty has instead made many vehicle manufacturers resort to hands-on practices to establish the *Jury Chart* for quality index, but it does not comprehensively include all acoustic comfort.

In reality, quality expert engineers observe wiper operation in a controlled laboratory, and match messy residues or smears left on the windshield against the jury chart. The point at issue here is that the current jury chart is rather a rule of thumb; it is neither construed in empirical justification nor how the user perceives the multi-modal quality (i.e., visual and acoustic) of the wiper operation. Thus, it is hard to tell whether the judgment of wiper operation quality with the jury chart realistically suggests what customers or users perceive.

To maintain high quality wiper operations in parallel with the user's perceived quality, the present study aims to develop a statistical inference model of the wiper operation quality. Here we propose a new concept to predict user's perceived quality based on the regression model, which considers both visible quality (VQ) and acoustic and vibration quality (AVQ), and is theoretically grounded on the cognitive ergonomics literature (e.g., sensory interactions: Hollier and Voelcker, 1997; Lees et al., 2012). The proposed model combines the two kinds of perceived information from the general wiper operating conditions, i.e., the level of visibility obtained by wiper operation, and noise or shudders during operation.

To illustrate our approach, this article comprises six sections. Section 2 provides some theoretical background and offers a literature review related to user's quality perception and wiper quality studies. Section 3 discusses a generic experimental setting, and Sections 4 and 5 describe the two experiments aimed at developing the multi-modal quality index model (Experiments 1 and 2). Section 6 compares the new model against the conventional jury chart; our predictive model is empirically validated if it can determine the customers' satisfaction with the wiper quality (Experiment 3). Section 7 offers our conclusions and describes further works.

2. Background

2.1. Perceived quality of wiper operation

There has been a substantial gap in understanding between what a wiper operation actually performs, how the expert evaluates its operation quality, and how the user actually believes the system should be. One of the participating research teams of the current study, Hyundai Motors Research Center (HMRC), recognized this problem previously and partially modified their jury chart to reflect more accurate visual and acoustic details of the wiper operation. Although the modified jury chart considers multimodal quality it was neither empirically established nor ecologically valid reported from the user's perspective.

Securing a driver's vision (i.e., driving visibility) through appropriate wiper operations is the most important functional quality for driving safety. In order to maintain high visibility through the windshield window, vehicle manufacturers have set up a highest standard. The two major players in the wiper system market, i.e., Bosch (1996) and Volvo (Fagervall and Nyman, 2000), have also established their own jury charts to satisfy the functional quality standards. They hold the assessment guidelines with several indicators, e.g., the number of stripes or smears left on the windshield window, the width of the stripes caused by the wiper, the number of droplets or residues left just after wiper operation, the area of the useful field of view (UFOV) after wiper operation, and so forth. However, the jury charts are highly subject to inter-rater variability. VisiNex™ (2010) thus tried to remove the potential rater's variability using a fine-tuned computer vision algorithm as a more ambitious method.

However, not only visibility, but also acoustic and vibration quality (AVQ) significantly affect the perception of wiper operation. Hardened wiper blades make both uncomfortable noises and shudders, for instance when they begin to warp or crack. HMRC developed three pivotal AVQ features together with the customer service department: *Normal working noise*, *Chattering*, and *Sanding sound*. None of these AVQ effects on wiper operation quality has been systematically studied, which was the main driving force of the present study. A series of studies done by Cerrato Jay (2007, 2009) investigates the sounds inherent in a vehicle during its operation. He claims that the acoustic quality of the wiper is expected to make audible noise, but it has to match users' expectations. Our focus in the present study is how the acoustic quality can be inserted (or overtaken) into the visibility quality of the wiper operation.

2.2. Human quality perception: cross-modal interactions

To fulfill expected levels of user satisfaction in the quality assessment, it is desirable to understand how humans perceive the visual and acoustic quality of wiper operations, and how sensory, perceptual, and cognitive processes act on quality evaluations, which is the main theoretical framework of the present study.

Early psychological studies (e.g., Hollier and Voelcker, 1997; Marks, 1978; Ryan, 1940; Walk and Pick, 1981) have been directed towards understanding multi-modality of human sensors (a.k.a. sensory interactions). In particular, many empirical outcomes have