

Measurement and Modeling of Perceived Gear Shift Quality for Automatic Transmission Vehicles

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ABSTRACT

This study was conducted to develop and validate a multidimensional measure of shift quality as perceived by drivers during kick-down shift events for automatic transmission vehicles. As part of the first study, a survey was conducted among common drivers to identify primary factors used to describe subjective gear-shifting qualities. A factor analysis on the survey data revealed four semantic subdimensions. These subdimensions include responsiveness, smoothness, unperceivable, and strength. Based on the four descriptive terms, a measure with semantic scales on each subdimension was developed and used in an experiment as the second study. Twelve participants drove and evaluated five vehicles with different gear shifting patterns. Participants were asked to make kick-down events with two different driving intentions (mild vs. sporty) across three different speeds on actual roadway (local streets and highway). After each event, participants were asked to complete the rating of the four descriptive terms as well as a comprehensive rating on the gear-shifting event. Along with this subjective evaluation, changes of mechanical properties during the event also were recorded. This included shift time and delay, acceleration profile, and jerk. Consequently, a series of statistical analysis revealed the relationship between each subdimension on subjective quality and their associated mechanical properties. Models of comprehensive shift quality, based on the ratings of the subdimensions for driving intentions and speeds, were also developed. The study provided a unique framework to assess subjective driving quality related to mechanical control variables in a multidimensional way, which is applicable to improve the quality of a vehicle.

CITATION: Jeon, B. and Kim, S., "Measurement and Modeling of Perceived Gear Shift Quality for Automatic Transmission Vehicles," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(1):2014, doi:10.4271/2014-01-9125.

INTRODUCTION

In automatic transmission vehicles, the gear-shifting event allows the vehicle operate over a wide range of speeds and is a key component for speed control in the vehicle. When changing gears, there is often a jolt in the vehicle's movement due to a transmission setting by the manufacturer to reduce response time excessively for the gear change. Conversely, drivers might perceive an unexpected delay in acceleration when the transmission control is programmed to provide drivers with a more smooth feeling. Due to this, it is required to find optimal configurations of gear shifting patterns to satisfy drivers across various conditions. However, the effort to satisfy drivers for shift quality also implies the importance of valid measurement technique to evaluate drivers' subjective perception of quality of the gear-shifting event, in forms of quantitative metric.

Historically, automobile companies have used trained drivers to assess the shift quality by rating it on a scale of 1-10 after driving the vehicles [1]. Another approach may include the

examination of variation of forward and backward acceleration data (G data) captured using acceleration sensors attached in a vehicle. Experts often use this approach on vehicle evaluation as an in-direct assessment method [2], [3]. There have also been studies to develop a useful measurement method [4]. Zhang et al. conducted a study to evaluate shift quality based on six different factors, these being shift time, acceleration, fuel economy, exhaust emission, jerk, and sound. The evaluation was applied to three different types of automobiles (average, premium luxury, and racing). They developed an artificial network to predict shift quality and validated it using the ratings of a professional driver [5].

The existing measures, however, have general limitations to assess drivers' subjective perception of shift quality. First, the results from a measurement using trained or professional drivers might not be extrapolated to the general driving population. Second, representative drivers often use a single scale assessment rating (e.g., a scale from 1, "extremely bad" to 10, "extremely good") despite the fact

that it may limit the evaluation of diverse psychological aspects influencing their perceptions of shift quality. Third, despite the fact that various dimensions of perceived shift quality were successfully captured using general drivers, the results do not provide the vehicle designers with solutions to improve the gear shift quality but rather present comparisons of the quality between competing vehicles. Therefore, there exists a need for further development of a shift quality metric to take into account drivers' common psychological factors. This metric will compose the perception of shift quality with an understanding of the relationship between mechanical variables of the gear shifting and the cognitive demands of drivers' subjective perception of shift quality so that vehicle designers can manipulate the mechanical properties to improve drivers' satisfaction. It was expected to be achievable through the application of Kansei Engineering [6].

Kansei Engineering was originally used to design new products based on customers' feelings and demands. Major activities for Kansei Engineering involve: 1) capturing the customers' common feelings about the product in terms of psychological estimation; 2) identification of design characteristics of the product; and 3) development of relationships between design characteristics and customers' feelings, which allow adjustments of the product to maximize customers' satisfaction [6]. In order to capture customers' feelings, the semantic differential (SD) method [7] was primarily used to measure and decompose the psychological meaning of the product. Even though Kansei Engineering has been developed and used in Japan, typically for designing products, a similar approach using SD has been used in many human factors studies. For instance, the NASA-TLX (Task Load Index) was developed by NASA to assess the level of human operators' mental workload [8]. Based on the SD method, the human workload was decomposed into six factors, including mental demand, physical demand, temporal demand, performance, effort, and frustration. These six subdimensions of perceived workload are then used to calculate the overall workload level. This measurement technique has been considered one of most validated measures to capture an operator's workload on a given task. Another example is the research on development and validation of multidimensional measures of display clutter [9], [10]. In that study, the investigators developed a metric for assessing subjective clutter in a flight cockpit display. They also used the SD method to identify six latent factors in the perception of clutter to develop a measure. They then demonstrated the validity of the measure through experiment and found relationships between the subdimensions of perception with pilots' performance and physical characteristics of the displays.

The objective of this study was to: 1) develop a multidimensional measure of perceived shift quality. This included discovering the underlying common psychological factors among drivers with respect to the perceived quality of gear-shift as well as generating a quantitative metric to represent drivers' subjective perception in a multidimensional manner; 2) validate the measure through an experimental study. It was expected that the multidimensional measure is

viable to express general shift quality; and 3) find relationships between various aspects of perceived shift quality and mechanical properties which were determined through physical characteristics of the vehicle based on the experiment data. This involved modeling approaches and is expected to support determining the best adjustment of transmission control variables in order to improve driver satisfaction. Consequently, the research encompassed two general studies, one for the measure development and another for experiment. However, it should be noted that even though the measure was built for evaluating general shift quality, its primary focus was on kick-down gear shifting events. A kick-down shift event refers to the automatic change of gear to a lower gear during abrupt acceleration in automatic transmission vehicles. It is considered to be one of the critical vehicle quality issues. Also, the present study was targeting the driving population in the U.S.

STUDY I- DEVELOPMENT OF MEASURE

In order to assess drivers' perceptions of shift quality, a measure consisting of semantic pairs was developed based on the SD theory [7].

Collection of Semantic Pairs

In order to identify the perceptual qualities of gear shifting that common drivers might internally define, we collected descriptor terms relative to the perceived shift quality from literature, magazine, and brainstorming. The terms were used as a base for identifying semantic pairs of terms that might represent a driver's concepts of gear shifting in making subjective assessment. An initial list of semantic pairs was generated, which consisted two antonymous adjectives. Several experts with substantial experience in vehicle testing using human subjects were then asked to validate the list of semantic pairs to determine whether it covered most possibilities in describing subjective shift quality. They were also asked to suggest other semantic pairs. Consequently, we identified the following 28 pairs of terms (See Table 1).

Table 1. List of semantic pairs

Smooth / Rough	Undisturbing / Disruptive
Responsive / Hesitant	Pleasing / Displeasing
Gentle / Harsh	High Quality / Low Quality
Fast / Slow	Faint / Distinct
Quick / Delayed	Precise / Loose
Fluid / Jerky	Slight / Significant
Comfortable / Uncomfortable	Lively / Quiet
Vigorous / Sluggish	Crisp / Vague
Unperceivable / Apparent	Balanced / Unbalanced
Controlled / Abrupt	Trustworthy / Untrustworthy
Strong / Weak	Relaxed / Tense
Delicate / Aggressive	Level / Bumpy
Firm / Soft	Economical / Uneconomical
Reliable / Unreliable	Infinitesimal / Evident

Data Collection

Based on the 28 semantic pairs of descriptor terms for shift quality, a survey form was developed to ask drivers to rate the shift quality of their personal vehicle. The survey form included 28 semantic pairs, using a 10-point scale, for rating of the shift quality. Figure 1 shows the sample of the survey form. The reason in which the survey asks the driver to rate their own vehicle rather than a controlled vehicle is not to evaluate each vehicle's shift quality but to assess the relationship between the semantic pairs in order to find primary common factors and groups of semantic pairs for describing the quality. Along with the semantic pairs, another 28 questions were included to rate the utility of each semantic pair, on a 10-point scale, for describing the quality. The analysis of this data was used to select representative semantic pairs among associated pairs in a group.

The survey data was collected on-line. Forty-three English speaking U.S. citizens with automatic transmission vehicles participated the survey. The survey group ranged in age from 20 to 60 years ($M=35.68$) and consisted of 19 males and 14 females.

Q1 *
1 2 3 4 5 6 7 8 9 10
Smooth ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Rough

Q2 *
1 2 3 4 5 6 7 8 9 10
Fluid ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Jerky

Q3 *
1 2 3 4 5 6 7 8 9 10
Gentle ○ ○ ○ ○ ○ ○ ○ ○ ○ ○ Harsh

Figure 1. Sample of survey form

Factor Analysis

Factor analysis using principal components was conducted to investigate the relationship among the 28 pairs of gear-shifting descriptors (principal components analysis is a specific form of factor analysis that does not make assumptions about the distribution of the response measure's variance). This analysis was intended to 1) examine the underlying factors or latent variables in drivers' perceptions of shift quality; and 2) determine how many factors are necessary to explain the pattern of variance in the perception of shift quality.

The ratings for the pairs of descriptor terms were submitted to a principal components analysis with an orthogonal equamax rotation. Through the analysis on scree plot and the cumulative eigen value, four factors were identified as latent variables explaining 76.4% of the total variance of the perception of shift quality. Table 2 shows the 4 factors and the factor loading values of each pair to the factor. Along with the factor loading values for each factor, the ratings on utility of pairs for describing shift quality, collected from the survey, were used to select the representative semantic pairs for each factor.

Consequently, 4 descriptor terms consisting of semantic pair were identified, including "Responsiveness (responsive/hesitant)", "Strength (strong/weak)", "Smoothness (smooth/rough)", and "Unperceivable (unperceivable/apparent)". This means that drivers' subjective perceptions on shift quality could be comprised of multidimensional meanings and the four latent factors are primary subdimensions of internal perception. Figure 2 and 3 show MDS (multidimensional scaling) map by projecting the multidimensional meaning space of the 28 terms in the driver's mental model into a 3-dimensional space and a 2-dimensional space, respectively. The figure also supports that the 28 terms can be grouped into 4 latent factors.

Table 2. Rotated component matrix

Term	Component			
	1	2	3	4
Trustworthy / Untrustworthy	0.864	-0.126	-0.185	0.236
Reliable / Unreliable	0.776	-0.112	-0.246	0.284
Precise / Loose	0.72	-0.289	-0.24	0.343
Pleasing / Displeasing	0.704	-0.404	-0.244	0.198
Responsive / Hesitant	0.691	-0.182	-0.358	0.282
High Quality / Low Quality	0.69	-0.447	-0.169	0.305
Balanced / Unbalanced	0.685	-0.405	-0.241	0.208
Controlled / Abrupt	0.584	-0.433	-0.176	0.393
Comfortable / Uncomfortable	0.576	-0.562	-0.394	0.083
Quick / Delayed	0.571	-0.172	-0.456	0.365
Fluid / Jerky	0.41	-0.779	-0.309	0.056
Gentle / Harsh	0.42	-0.778	-0.276	0.117
Relaxed / Tense	0.273	-0.777	-0.241	0.184
Smooth / Rough	0.462	-0.762	-0.228	0.027
Delicate / Aggressive	-0.032	-0.639	-0.601	0.073
Level / Bumpy	0.488	-0.623	-0.421	0.11
Faint / Distinct	0.084	-0.621	-0.588	-0.015
Undisturbing / Disruptive	0.581	-0.599	-0.395	0.035
Lively / Quiet	-0.051	0.477	0.292	0.433
Economical / Uneconomical	0.335	-0.455	-0.208	0.397
Unperceivable / Apparent	0.227	-0.097	-0.913	-0.061
Infinitesimal / Evident	0.213	-0.051	-0.904	-0.079
Slight / Significant	-0.097	-0.618	-0.687	0.154
Strong / Weak	-0.016	0.04	0.24	0.807
Vigorous / Sluggish	0.45	-0.256	-0.128	0.715
Fast / Slow	0.176	-0.271	-0.347	0.687
Firm / Soft	0.061	0.42	-0.012	0.676
Crisp / Vague	0.566	-0.125	0.166	0.593

Note: Shaded cells indicate the factor loading value of variables exceed 0.5 toward each factor.

Development of Measure

Based on the four latent factors and the semantic pairs found using factor analysis, a multidimensional measure of perceived shift quality was developed. The set of shift quality descriptor terms was used as an anchor in the collection of bipolar subjective rating scales covering the underlying dimensions. The scales were integrated into an overall quality index, which required drivers to rank the importance of each dimension. Therefore, the measure was consisted of two forms, a ranking

form and a rating form. The ranking form was to collect the importance of each dimension for each individual (see [Appendix](#)). This form was completed once all experimental trials were finished. The evaluators (drivers in the study) were asked to select which subdimension term of two subdimensions terms was most important to them. Thus, the weight of each subdimension was calculated based on number of selected terms among 8 pair-wise comparisons ($8=4C_2$). The rating form was used to capture the subjective ratings on each subdimension consisting of the semantic pairs while using a bipolar semantic scale. The rating form was completed after finishing each specific task event during the experimental trials (see [Appendix](#)). The ranking and ratings for specific gear-shifting events were combined in an overall shift quality score (rank-weighted sum of ratings across dimensions). This measurement approach was very similar to the design of examining other psychological phenomenon, such as the NASA-Task Load Index (TLX) for measuring subjective mental workload [8] and the display clutter matrix for assessing subjective perception of visual display clutter [9][10]. However, the measure developed in the present study was used to collect data using actual vehicles.

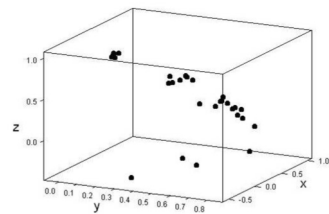


Figure 2. Multidimensional scaling map of descriptor terms in 3-dimensional space

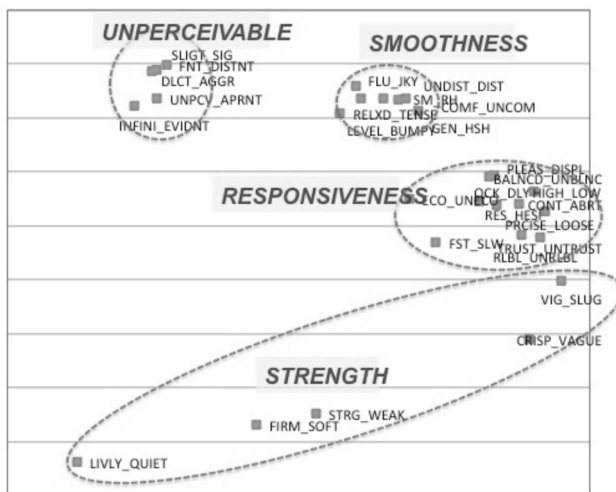


Figure 3. Multidimensional scaling map of descriptor terms in 2-dimensional space

STUDY 2- EXPERIMENT

An experiment was conducted to validate the multidimensional measures for assessing perceived shift quality and to identify the relationship between the drivers' perception of quality and the mechanical properties in the vehicle during the gear-shifting event.

Method

Equipment

Three types of current mid-size sedan vehicles were selected for the experiment (Vehicle A, B and C). The vehicles were equipped with similar engines (2400cc) and body sizes. Since vehicle A was a product of the sponsoring research company, three (3) different Transmission Control Units (TCUs) were prepared and used in vehicle A by replacing them throughout the experiment. The three TCU's were programed to generate different gear shifting patterns, including slow-smooth (A1), fast-rough (A3), and the regular pattern which is applied for the vehicle in market (A2). Consequently, five (5) vehicle samples (A1, A2, A3, B, and C) were used in the experiment. Each vehicle had a different calibration for gear-shifting response patterns. In order to prevent a subjective bias from vehicle brands on the rating of shift quality, substantial instructions were provided to the participants.

During the kick-down gear shifting events, the mechanical data, such as the vehicle's speed and gear shifting profile, were captured through an OBD (On-Board Diagnostics) interface. In addition to this, an accelerator sensor was attached in the vehicle to capture longitudinal acceleration. The data from the OBD interface and the acceleration sensor were recorded in real-time in a portable workstation during the experiment. The sampling rate of these mechanical data was 100 Hz.

Participants

The study was focusing on U.S. driver population therefore twelve English-speaking drivers participated in the experiment. The drivers were balanced across age and gender. There were 6 males and 6 females. Of the drivers, 6 were young drivers (ranging in age from 21 to 37 years) and 6 were older drivers (ranging in age from 52 to 59 years old). The mean age of the 12 participants was 40.7 years of age. The average years of driving experience was 23.3 years with a standard deviation of 13.4 years. The driving experience years for young drivers and old drivers were 11.2 years (with standard deviation of 5.2 years) and 35.5 years (standard deviation: 3.1 years), respectively.