Expert Systems with Applications 40 (2013) 800–810

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A fuzzy logic based approach for modeling quality and reliability related customer satisfaction in the automotive domain

Rahul Chougule *, Vineet R. Khare, Kallappa Pattada

Diagnosis & Prognosis Group, India Science Lab, General Motors Global Research and Development, GM Technical Centre India Pvt. Ltd., Creator Building, International Technology Park, Whitefiled, Bangalore 566066, Karnataka, India

ARTICLE INFO

Keywords:
Personal Quality and Reliability Satisfaction (*PQRS*)
Fuzzy logic
Grid search
Automotive
Warranty data

ABSTRACT

This paper presents an approach to assess quality and reliability related customer satisfaction from field failure data at each individual customer level. The quality satisfaction has been modeled based on number of failures and severity of failures, while, reliability satisfaction has been modeled based on number of visits to dealer and time span between visits. The satisfaction modeled at an individual vehicle (customer) level is further aggregated to a vehicle model level to determine overall satisfaction of customers with that specific vehicle model. A fuzzy logic approach is used to construct the satisfaction model. A grid search technique is used to tune the model parameters such that the output of the model for specific vehicle models matches with survey based ratings assigned to the vehicle models.

1. Introduction

In the context of global competition, there has been an increasing awareness in improving the processes which are directly linked with customer satisfaction. Customer relationship management (CRM) has emerged as a prominent aspect of business. In this regard, one of the notable developments of quality movement is assessment of the customer satisfaction. Hernon and Whitman (2001) defined satisfaction as a sense of contentment that arises from an actual experience in relation to an expected experience. Customer satisfaction measures customer's subjective experience with a product and service. Two different conceptualizations, namely (a) transaction-specific and (b) cumulative have been reported in the literature (Andreassen, 2000; Boulding, Kalra, Staelin, & Zeithaml, 1993). Transaction-specific concept refers to satisfaction as the evaluation of single experience (Oliver, 1993). In contrast, cumulative satisfaction involves satisfaction as customer's up to date experience with a product or service (Fornell, Johnson, Anderson, Cha, & Bryant, 1996).

In literature, several conceptual models have been developed to define quality in terms of customer satisfaction, especially, in service sectors such as banking, telecom. However, very limited scientific literature has been reported on quantifying the customer satisfaction. The reported work on assessment of customer satisfaction in automotive domain is further scarce. Several factors (such as vehicle appeal, performance, ownership cost, service at dealership, quality and reliability) contribute to the customer satisfaction in automotive domain. However, factors related to quality and reliability contribute more than 40% in shaping customer perception and satisfaction (J. D. Power Associates., 2009) as depicted in Fig. 1. Generally speaking, in automotive domain, quality and reliability are assessed based on number of failures in the field, which are expressed as incidents per thousand vehicles (IPTV) or problems per hundred vehicles (PPH). Warranty data is often used to get the estimates of IPTV or PPH. Further, automotive manufacturers conduct surveys and also refer to published survey results (such as J.D. Power, Consumer Reports) for getting insight into the customer satisfaction. The customers define quality and reliability of a product from his or her experience with the product. Counting the number of problems per thousand (or per hundred) vehicles may be a good indication of quality. However, in the current challenging business scenario, it is essential to assess customer satisfaction at each customer level which drives the decision making process related to purchase of vehicle. However, currently very limited emphasis is given on measuring individual customer perception and satisfaction. The following quote of Lord Kelvin reflects the importance of measurement or evaluation:

"*When you can measure what you are speaking about and express it in numbers, you know something about it…(otherwise) your knowledge is a meager and unsatisfactory kind; it may be beginning of knowledge, but you have scarcely in thought advanced to the stage of science.*"……Words of Lord Kelvin (1824–1907).

In this regard, a quantified approach is needed to evaluate the satisfaction related to quality and reliability at an individual customer level. This will help to identify dissatisfied customers and to provide individual customer care which will result into improved brand perception and brand loyalty.

* Corresponding author.
E-mail address: chougulerahulg@gmail.com (R. Chougule).

0957-4174/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2012.08.032

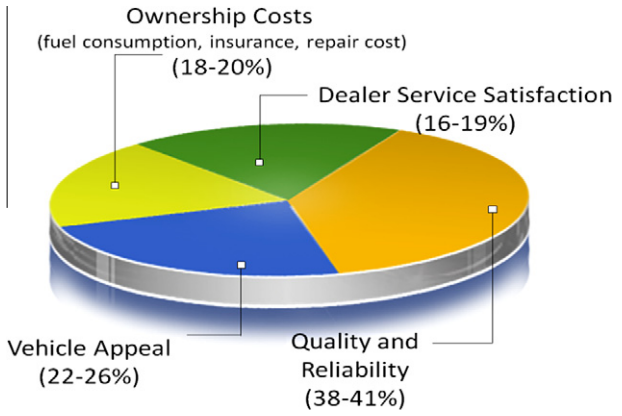

Fig. 1. J.D. Power Vehicle Ownership Satisfaction Study: The impact of service/repair on customer satisfaction.

In this paper, we present a novel approach to model customer satisfaction at an individual customer level from the field failure data that Original Equipment Manufacturers (OEMs) maintain. Here, we focus on modeling quality and reliability satisfaction. These have been expressed in terms of Personal Quality Satisfaction (*PQS*) and Personal Reliability Satisfaction (*PRS*). These indices have been aggregated to measure customer satisfaction in terms of *PQRS* (Personal Quality and Reliability Satisfaction) at an individual vehicle level and at vehicle model level. The customer satisfaction at an individual level has been modeled using fuzzy logic approach. Grid search technique has been used to tune various parameters in the satisfaction model. The overall objective of the parameter tuning is to minimize the difference between satisfaction values obtained from the proposed model and the target satisfaction ratings available in published by external agencies. In Section 2, we provide state-of-the-art review of different disciplines that are used in our approach. In Sections 3 and 4, we present a customer satisfaction model and an approach that has been used to tune various parameters related to satisfaction. Section 5 presents results while conclusions and future directions are presented in Section 6.

2. Related work

A significant work on relating customer satisfaction with consumer loyalty has been reported primarily in service sector such as banking, hospitability, E-commerce, and telecommunications (Danaher and Gallagher, 1997; Hallowell, 1996; Shankar, Smithb, & Rangaswamy, 2003). However, a very limited work has been reported on quantitative assessment of customer satisfaction. The work on assessment of customer satisfaction at individual customer level is further scare. One of the most cited models in the literature is American Customer Satisfaction Index (ACSI). Here, the satisfaction is measured on a 0 to 100 scale by several questions that assess customer's evaluation. Looking at the indices and the impacts, users can determine which drivers of satisfaction would have the most impact on customer loyalty (American Customer Satisfaction Index (ACSI), 2009).

In automotive domain, customer satisfaction index from J.D. Power and Associates, and Consumer Reports (CR) are popularly referred by consumers and OEMs to get insight into the customer satisfaction related to particular vehicle model or brand (Consumer Reports, 2010). These reports compare performance of various automotive makes and models in terms of customer satisfaction. These reports are based on surveys which assess the failures experienced by the customers. For example, the Initial Quality Study (IQS), conducted yearly by J.D. Power and Associates, provides information on new-vehicle quality after 90 days of ownership. Owners are surveyed regarding problems with their new vehicles (J.D. Power Associates., 2009). Similarly, J.D. Power and Associates Vehicle Dependability Study (VDS) focuses on problems experienced by owners of three-year-old vehicles. In these studies, the relative performance is measured using a "problems per 100 vehicles (PP100)" metric. A lower PP100 score indicates better performance and a higher PP100 score indicates worse performance.

Consumer Reports Organization is another independent organization that conducts surveys and lab tests to come up with product reviews and ratings on cars, electronics and other home appliances (Consumer Reports Organization., 2012). For new and used cars, Consumer Report publishes reliability ratings annually. Reliability scores are derived from annual surveys from subscribers of Consumer Reports based on incidences of failure in the last 12 months. Using these surveys, reliability ratings (such as average, above average, worse than average) are assigned to various vehicle models under consideration.

These survey based methods often rely on a smaller sample of population and may not always represent the real world facts. In contrast to these survey based methods, the current work relies on warranty data to estimate satisfaction level at an individual customer level and then aggregate it over a particular make or the model. In the current work, customer satisfaction has been modeled using fuzzy logic approach while grid search technique has been used for tuning various parameters in this model. Hence, these techniques have been reviewed in the next subsections along with their applications in related areas.

2.1. Fuzzy logic

Fuzzy set theory was introduced by Zadeh to deal with the decision problems in the absence of sharply defined criteria (Zadeh, 1965). It was developed based on the premise that, key elements in human thinking are not numbers, but linguistic terms or fuzzy sets that are not precisely defined (Zimmerman, 1982). The fuzzy set theory states that, a fuzzy number A is a special fuzzy subset of real numbers R. Its membership function fA (x), is a continuous mapping from R to an interval [0,1]. Fuzzy logic gained acceptance because of its capability to handle impreciseness, and representing and manipulating linguistic variables (Dubois, 1978).

It has been explored in Quality Function Deployment (QFD) for modeling customer preferences/attributes (CAs) and engineering characteristic (ECs) that are expressed in linguistic terms. Khoo and Ho (1996) first proposed a framework for fuzzy QFD systems. Wang (1999) proposed a fuzzy ranking relation to model the imprecise preference relations between design requirements. Vanegas and Labib (2001) reported a fuzzy QFD model to derive target values of ECs based on fuzzy numbers that represent the imprecise nature of the judgments. Ramasamy and Selladurai (2004) developed a fuzzy rule-based knowledge system that defines the relationship between the ECs and the CAs. The fuzzy logic approach has also been used to model environmental concerns in QFD (Kuo, Wu, & Shieh, 2009).

Wong (2001) employed fuzzy c-means (FCM) clustering method to identify different customer segments by mining parameters related to customers' needs, characteristics and behavior. In this work, fuzzy theory is also used in quantifying the linguistic parameters. Weber and Weber and Crespo (2005) presented a dynamic data mining methodology based on fuzzy c-means for customer segmentation. Shah, Roy, and Tiwari (2006) developed fuzzy expert system 'Customer and Service Advisor (CSA)' to categorize and identify type of customer and then identify the advisor based on the age, demographic, experience, business value and behavioral attributes. Here, fuzzy logic is used to model the attributes that