Int. J. Production Economics 139 (2012) 180–195

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

Hazard rate models for early detection of reliability problems using information from warranty databases and upstream supply chain

Chongwen Zhou [a], Ratna Babu Chinnam [b,*], Alexander Korostelev [c]

[a] Faurecia Automotive Seating, 2380 Meijer Drive, Troy, Michigan 48084, USA
[b] Department of Industrial & Systems Engineering, Wayne State University, Detroit, Michigan 48202, USA
[c] Department of Mathematics, Wayne State University, Detroit, Michigan 48202, USA

ARTICLE INFO

Article history:
Received 1 March 2011
Accepted 12 April 2012
Available online 5 May 2012

Keywords:
Warranty
Hazard rate
Proportional hazard model
Early detection
Supply chain

ABSTRACT

This paper presents a statistical methodology to construct a model for early detection of reliability problems using information from warranty databases and upstream supply chain. This is contrary to extant methods that are mostly reactive and only rely on data available from the OEMs (original equipment manufacturers). The paper proposes hazard rate models to link upstream supply chain quality/testing information as explanatory covariates for early detection of reliability problems. In doing so, it improves both the accuracy of reliability problem detection as well as the lead time for detection. The proposed methodology is illustrated and validated using real-world data from a leading Tier-1 automotive supplier.

1. Introduction

The automotive industry spends roughly $10–$13 billion per year in the U.S. on warranty claims (Arnum, 2011b) and up to $40 billion globally (MSX, 2010), consuming roughly 1%–5.2% of original equipment manufacturers' (OEM) product revenue and roughly 0.5%–1% of suppliers' product revenue (Arnum, 2011a). Warranty claims refer to customer claims for repair or replacement of, or compensation for non-performance or under-performance of an item, as provided for in its warranty document. Historically, the leading Japanese automotive OEMs, i.e., Honda and Toyota, had significantly lower warranty cost relative to product revenue than their U.S. counterparts. For example, between the years 2003 and 2011, the warranty costs for Toyota and Honda were around 1%–1.7% of product revenue, whereas the costs for the U.S. OEMs (Ford, GM, and Chrysler) were between 2.2% and 5% (Arnum, 2011a). OEMs typically incur 70% of warranty costs, including those associated with engineering, manufacturing, and suppliers (MSX, 2010). Early detection of reliability problems can help OEMs and suppliers take corrective actions in a timely fashion to minimize warranty costs and loss of reputation due to poor quality and reliability. A compelling example is the case of the recent product recalls from Toyota in the U.S. and around the world, attributed to pedal assembly and floor mat entrapment issues, involving 12 vehicle nameplates and 8.5 million vehicles produced between 1998 and 2010 (Takahashi, 2010; Toyota, 2010), costing the company over $2 billion (Carty, 2010) and caused its warranty costs to jump to around 2.5% of its product revenue (Arnum, 2011a).

Improving reliability and reducing warranty costs is the joint objective and responsibility of both OEMs and suppliers. This is especially true when the recent trends show OEMs have increased pace of shifting warranty cost to their suppliers (Arnum, 2011a). A highly engineered product such as an automobile consists of many modular systems (e.g., electrical, powertrain, chassis, seating), subsystems (e.g., wiring harnesses, alternators, motors), and thousands of components that are supplied through an extensive supply network. Before a vehicle is produced, these systems, subsystems, and components have to undergo design, testing and build at supplier and OEM sites. Therefore, information regarding reliability problems doesn't just start appearing from vehicles reaching customer's hands, but can start far early at suppliers' sites and are heavily influenced by operations at all tiers of suppliers. For example, a quality lapse in a supplier's plant may be the first indication of a reliability problem and an unusually high warranty claim rate. There are rich sources of upstream production quality/testing information regarding components and sub-systems residing in the supplier network and accumulating long before the final vehicles are assembled. Fig. 1 illustrates some of the major sources of information for developing early reliability problem detection models in the automotive industry.

Reliability can be defined in several ways, depending on the scope of the product life-cycle under consideration (Murthy, 2010):

* Corresponding author. Tel.: +1 313 577 4846; fax: +1 313 578 5902.
E-mail addresses: chongwen.zhou@faurecia.com (C. Zhou), ratna.chinnam@wayne.edu (R.B. Chinnam), apk@math.wayne.edu (A. Korostelev).

0925-5273/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2012.04.007

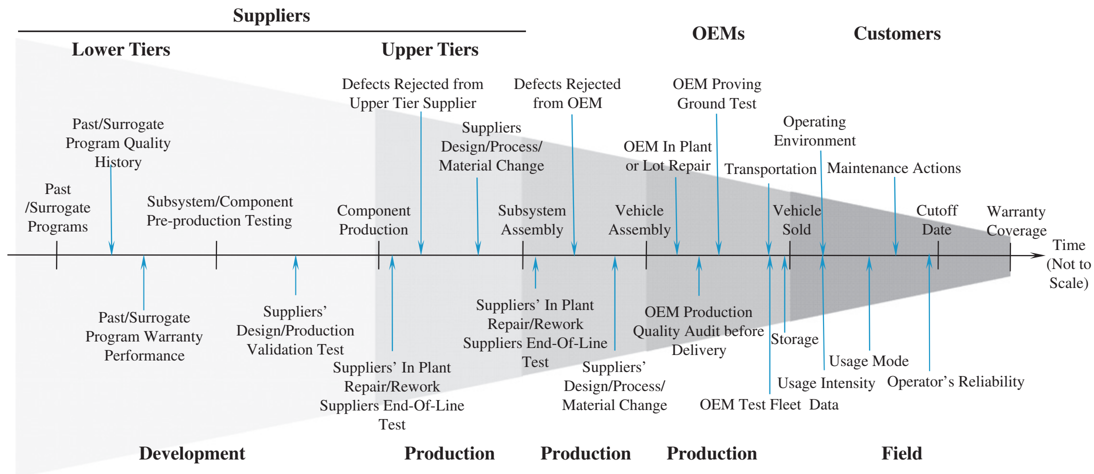

Fig. 1. Data sources for modeling reliability problems from supply network upstream to customer downstream; Adopted from Majeske (2007), Murthy (2010).

design reliability, inherent reliability (accounting for manufacturing and assembly errors), reliability at sale (accounting for damage during transportation and storage), and field reliability (accounting of customer usage behavior and environment). It is noted in the literature that the percentage of warranty claims due to human factors (such as user misuse, neglect, fraud or lack of training on product operation) in the field can be as large as 10% (Wu, 2011). However, this type of information is not readily available in several industries including the automotive, and in particular, not for Tier-1 and upstream suppliers. It is also true that not all warranty claims might stem from a reliability problem and not all failed items lead to a claim. However, warranty claim codes (that identify the reason for the claim and type of warranty work performed) allow us to make a strong connection. Hence, warranty claims can be used as surrogate indicators of product reliability.

If the upstream information from the OEM and the supply chain can be utilized in a statistical framework to correlate to reliability problems indirectly through warranty claims, the power of an early reliability problem detection model should improve. Such an early warning system can also be used to monitor the effectiveness of corrective actions. While there is a growing body of literature on warranty modeling and forecasting, to the best of our knowledge, there is no model in the literature that explicitly links information from the supplier network to improve early reliability problem detection.

The primary contribution of this manuscript is the introduction of a statistical modeling framework that explicitly utilizes upstream supply chain information from suppliers to not only allow early detection of reliability problems indirectly through warranty claims monitoring but also to aid in predicting the warranty claim rates. By utilizing hazard rate models, upstream supply chain quality/testing information is directly linked to expected warranty claims as explanatory covariates to achieve this goal. This research is from a supplier's point of view, and hence focuses more on linking warranty claim rates to design and inherent reliability problems. This upstream supply chain information is readily available to suppliers. As stated earlier, information from the field regarding customer usage behavior and environment is not available in several industries including the automotive, in particular for suppliers. However, the statistical modeling framework from this research can be extended to include any available and relevant sale/field reliability information as explanatory covariates. While much of this research focuses on application of the proposed reliability problem detection models to the automotive industry, the models are also relevant to other industries that rely on a supply network to build parts of the product.

The rest of this paper is organized as follows. Section 2 reviews relevant literature. Section 3 describes the structure of suppliers' manufacturing and quality/testing data sources that might be indicative of reliability problems, and in turn, future warranty claims. Section 4 outlines the proposed methodology of utilizing hazard rate models to correlate upstream data sources to warranty claims. Section 5 develops an enhanced early reliability problem detection scheme by incorporating upstream suppliers' quality/testing data. Section 6 reviews the performance of the proposed method through a case study. Section 7 provides summary remarks and directions for further study.

2. Literature review

Detection of a reliability problem through warranty claims monitoring often involves several steps: (a) Statistical modeling of warranty claims so that those factors influencing product reliability can be selected and the parameters in the model can be estimated; (b) Historical warranty claim datasets from similar products and/or subject matter experts (SMEs) in the absence of historical information can be useful for establishing 'a priori' model parameters, (c) Critical values for the parameters for monitoring are set to balance power of problem detection and false alarm probability, and (d) Observed parameters for the current product model are compared against the critical values to trigger out-of-control signals.

There is a growing body of literature discussing statistical modeling of warranty claims. In the automotive industry, as the number of expected warranty claims is often small under any given failure mode (claim rates are typically measured as claims per thousands of vehicles) compared to the large number of vehicles in field, from a reliability point of view, such warranty claims are often treated as rare and independent events, making the Poisson model an appealing statistical model for warranty claims. Since the seminal paper by Kalbfleisch et al. (1991) that proposed a Poisson model to analyze warranty claims, many papers have been authored that focus on predicting future warranty claims for the remainder of warranty life based on existing/past warranty claims for the early portion of warranty life. Models have been developed to also deal with such issues as warranty report delay (Kalbfleisch and Lawless, 1991; Lawless, 1994); (Lawless, 1998), sales delay (Lawless, 1994; Majeske et al.,