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Invited Review

Maintenance models in warranty: A literature review

Mahmood Shafiee [a,*], Stefanka Chukova [b]

[a] Department of Mathematical Sciences, Chalmers University of Technology and University of Gothenburg, SE-412 96 Göteborg, Sweden
[b] School of Mathematics, Statistics and Operations Research Victoria University of Wellington, Wellington, New Zealand

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ABSTRACT

Along with increasing the warranty period for complex systems, reducing the warranty servicing costs has become an issue of great importance to the manufacturers. One possible way to reduce the expected warranty servicing cost is by making sound decision on the product warranty and maintenance strategies. Therefore, warranties (basic warranty and extended warranty) and maintenance (corrective and preventive) are strongly interlinked and of great interest to both manufacturers and customers. This paper is the first identifiable academic literature review to deal with warranty and maintenance. It provides a classification scheme for the articles that link warranty and maintenance published between 2001 and 2011 covering 44 journals and proposes a taxonomy scheme to classify these articles. Nine hundred articles were identified for their relevance to warranty and were carefully reviewed. One-hundred and twenty-two articles were subsequently selected for their relevance to maintenance and included in the classification.

1. Introduction

In today's competitive market, many products are sold with a warranty. A product warranty is a contract between the buyer and the product manufacturer. It requires manufacturers/dealers to repair, replace or provide compensation to the buyers in the case of product failure for a pre-specified time period, referred to as the 'warranty period'. According to Murthy and Blischke [1], two important roles of warranty are (i) protection (for the consumers against defective items and for the producers against consumers' excessive claims) and (ii) promotion (for product differentiation by producers and by consumers).

Recently, due to the rapid technological development and fierce competition in the marketplace, the manufacturers are under pressure to extend the coverage period of their after sale services by offering long-term warranty. From the beginning of the 20th century, the warranty period offered by the manufacturers (dealers) has been progressively increasing. For example, in the early 1980s, the warranty period for airplanes was 12 months/1000 flight-hours, this changed to 30 months/2500 flight-hours in the 1990s, and currently it varies from 60 months/5000 flight-hours to 120 months/10,000 flight-hours (http://www.warranty-week.com). Nissan has been offering 10 year/unlimited mileage warranty for cars (Nissan warranty information Booklet, 2011). A number of manufacturers of 'Micro–Electro-Mechanical Systems (MEMSs)' have started offering *lifetime* warranties for their products. With long-term warranties, items are warrantied for a significant part of their useful lives, and this implies that failures due to manufacturing defects during infant mortality, random failures during useful life and degradation failures during wear-out can occur within the warranty period.

A longer warranty term usually attracts more customers, but at the same time it involves additional servicing costs (called 'warranty servicing' costs) to the manufacturers. The warranty servicing cost is the cost of rectifying a faulty item during the warranty period. Depending on the product and manufacturer, this cost can vary between 2% and 10% of an item's sale price. For example, American manufacturers spend over $25 billion–about 2% of their revenue-annually on warranty services [2]. According to the 2009 General Motors annual report, the company had total revenue of US$104.2 billion and the future warranty cost on sold cars was estimated to be US$2.7 billion-about 2.6% of the revenue. As the warranty servicing costs directly affect the manufacturer's profit, finding an effective strategy to reduce warranty servicing costs has become an issue of great importance to the manufacturers. One possible way to reduce the expected warranty servicing cost is by making sound decision on the product maintenance strategies.

Maintenance plays an important role in keeping product availability, reliability and quality at an appropriate level. Also, it addresses the product safety requirements. In the literature, maintenance is classified into two main types: corrective and preventive. Corrective maintenance (CM) occurs after item's failure and restores it to an operational state; preventive maintenance

* Corresponding author. Tel.: +46 31 772 5361.
E-mail addresses: mahsha@chalmers.se (M. Shafiee), stefanka.chukova@vuw.ac.nz (S. Chukova).

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(PM) is performed before item's failure and aims to reduce item's degradation and its risk of failure. If the useful life of a product is relatively short, then its (basic) warranty is also relatively short, and warranty servicing should involve only CM actions. If a product has a long useful life, then an extended warranty could be also relatively long and, the manufacturer can reduce warranty servicing costs by performing effective PM actions. Optimal maintenance strategies need to be viewed from a life cycle perspective (from buyer's and manufacturer's viewpoints), and hence, there is a close link between warranties (basic warranty and extended warranty) and maintenance (CM and PM).

The literature that links warranty and maintenance is significant, but limited, in comparison with the literature on these two topics in separate. Both warranty and maintenance have received increasing attention over the period 2001–2011. Studies on product warranty includes (a) four reference books: Murthy and Blischke [3]; Thomas [4]; Rai and Singh [5]; Blischke et al. [6] (b) seven book chapters: Murthy and Blischke [7]; Lyons and Murthy [8]; Murthy and Djamaludin [9]; Murthy and Jack [10]; Wang and Pham [11]; Murthy and Jack [12]; Iskandar and Jack [13] (c) four review papers: Murthy and Djamaludin [14]; Murthy et al. [15]; Karim and Suzuki [16]; Murthy [17], and more than nine hundred journal papers. The literature on maintenance policies is also extensive. Several review papers on maintenance have appeared during 2001–2011 period. For a review of existing literature on maintenance policies, we refer the readers to Wang [18]; Nakagawa [19]; Garg and Deshmukh [20]; Nakagawa [21] and the recent review by Sharma et al. [22].

In the existing review papers on both warranty and maintenance, there is a lack of a broader perspective to look at warranty and maintenance in an integrated and unified manner. This paper is the first identifiable academic literature review to deal with warranty and maintenance. It provides a classification scheme for the articles published between 2001 and 2011. Nine hundred articles were identified for their relevance to warranty and were carefully reviewed. One-hundred and twenty-two articles were subsequently selected for their relevance to maintenance and classified to three main categories: *warranty servicing with only CM actions*, *warranty servicing with both CM and PM actions* and *maintenance during the post-warranty period*.

The paper is organized as follows: first, we describe the classification process used in the study; second, articles on warranty and maintenance are analyzed and the results of the classification are reported; and finally, we outline our conclusions and give a brief discussion of future research topics.

2. Classification process

2.1. Classification methodology

As the nature of research in warranty and maintenance is difficult to confine to specific disciplines, the relevant materials are scattered across various journals. Consequently, the following online journal databases were searched by *text mining* techniques to provide a complete bibliography of the academic literature related to warranty and maintenance.

ABI/INFORM Global–ProQuest; Academic Search Premier; Blackwell Synergy; Business Source Premier–EBSCOhost; Compendex (Engineering Village)–Elsevier Engineering Information; Emerald Fulltext; IEEE Transaction; ISI Web of Knowledge; NTIS-Ovid (SilverPlatter); Scopus–Elsevier; Springer Link; and Wiley InterScience.

At first, the literature search was based on the descriptor 'warranty', which originally produced approximately nine hundred articles. Conference papers, masters and doctoral dissertations, textbooks and unpublished working papers were excluded, as academics and practitioners most often use journals to acquire information and disseminate new findings. Then, the full text of each article was reviewed carefully to eliminate those that were not related to 'maintenance'. Finally, 122 articles published in 44 academic journals were selected for their relevance to warranty and maintenance.

2.2. Selection criteria and evaluation framework

Each of the selected 122 articles was reviewed and classified according to the proposed classification framework by two independent researchers. The classification process consisted of four phases: (i) online database search, (ii) initial classification by first researcher, (iii) independent verification of classification results by second researcher; and (iv) final verification of classification results by both researchers.

If there were a discrepancy in classification, each of these articles was then discussed until an agreement was reached on how the article should be classified. The selection criteria and evaluation framework are shown in Fig. 1.

The collection of articles was analyzed in accordance with maintenance models in warranty, by year of publication and according to the journal in which the article was published.

2.2.1. Distribution of articles by year of publication

The number of articles by year of publication is shown in Table 1. There is a clear upward trend of the number of publications related to maintenance models in warranty from 2001 to 2011. In 2011, the number of publication increased by 214% compared to 2001.

2.2.2. Distribution of articles by journal in which the articles were published

Table 2 shows the distribution of articles by journal. Articles related to warranty and maintenance are distributed across 44 journals. Of these, *European Journal of Operational Research*, which focuses on the development and application of operational research (OR) and decision making, contains around 9.01% (11 of 122 articles) of the total number of published articles.

2.3. Classification framework

We first propose a framework to classify these articles and then provide a review. The literature involving warranty and maintenance can be organized into the following three main categories:

Warranty servicing with only CM actions
The papers in this category [23–61] deal with the optimal choice of CM action (repair vs replace by new, different levels of repair) to minimize the expected warranty servicing cost per unit sale.
Warranty servicing with both CM and PM actions
These papers [62–127] deal with the use of PM actions in order to achieve a trade-off between the additional PM costs and the reduction in the expected warranty servicing costs.
Maintenance during the post-warranty period
The papers in this category [128–144] deal with the role of PM actions during the post-warranty period in order to minimize life cycle costs (LCCs).

A graphical classification framework on maintenance models in warranty is proposed and shown in Fig. 2.