On assumptions in optimisation of warranty policies

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Abstract. Optimisation of warranty policy has been a hot research topic in both operations research and statistics communities since warranty providers hope to balance cost-benefit analysis in the nowadays competitive market. Some assumptions are inevitably needed for such research. Most of the existing publications, however, make assumptions that may not be true in practice, based on which biased decision may be made. This paper discusses pitfalls in the assumptions, which include causes of warranty claims, pattern of warranty claims, warranty claim models, field reliability vs product reliability, the relationship between usage and age in 2-dimensional warranty. A real-world example is used to elaborate the arguments.

1. Introduction

Warranty is a duty attached to a product and requires manufacturers to offer pre-specified compensation to buyers when a product fails to perform its designed functions under normal use within the warranty period. Nowadays, product warranty becomes increasingly important in consumer and commercial transactions, and is widely used and serves many purposes (Wu 2013). For example, Congress in the USA passed the Magnusson Moss Act, the European Union (EU) passed legislation requiring all a two-year warranty for all products, and in the UK the annual sales volume of extended warranties is more than £1 billion.

Warranty expense is one of the operating expenses for manufacturers. A product might be sold with a warranty agreement and the manufacturer needs to cover labour and parts needed for repairs or replacement within the warranty period. As a consequence, warranty incurs tremendous cost in the manufacturing industries. For example, the automotive industry spends roughly \$10–\$13 billion per year in the U.S. on warranty claims and up to \$40 billion globally (MSX International Inc 2010).

Warranty policy, which concerns with warranty period and optimisation of maintenance policy of a product during its warranty period, is made based on the estimated reliability of the product and its associated costs. The success of a warranty policy hinges heavily on the well-orchestrated interplay of the good reliability models, cost information, and the effective use of these models.

In the literature, there is considerable research on warranty optimisation (see (Su, Wang 2016, Shafiee, Chukova 2013), for example), which forms a hot research topic in both operations research and statistics communities since warranty providers hope to balance cost-benefit analysis in the nowadays competitive market. Some assumptions are inevitably needed for such research. Most of the existing publications, however, make assumptions that may not be true in practice, based on which biased decision may be made.

This paper discusses the validity of those assumptions, which include causes of warranty claims, pattern of warranty claims, warranty claim models, field reliability vs product reliability, the relationship between usage and age in 2-dimensional warranty.

2. Assumptions in optimisation of warranty policies

Optimisation of warranty policy replies on efficient and unbiased reliability models and accurate information on relevant costs. Unfortunately, in reality, to obtain such models and cost information is very challenging (see (Ye, Ng 2014), for example), due to various constraints, as discussed in the following.

2.1 Information of cost

Many authors optimise warranty policies based on minimising the expected cost relating to a specific topic such as lifecycle cost or maintenance cost, which is vitally important due to the severe market competiveness. In doing those, various cost information is required. Cost information used to optimise expected long-run cost per unit time is commonly uncertain in practice. For example, repair cost or

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replacement cost used to optimise preventive maintenance policy can be hard to estimate. Similar optimisation problems can be burn-in policy optimisation, warranty policy optimisation, and maintenance policy optimisation. Hence, precise cost information and reliability models with good quality are is usually hard to obtain, which makes it hard to use existing approaches. As a result, optimisation can bias decision making and hence huge resources (i.e., capital, raw materials, etc) are wasted. A literature review of lifecycle cost optimisation has provided very little information specifically in this area.

The difficulty of acquiring cost information becomes more challenging for products with long-term warranty. During the long warranty coverage, cost of repair and cost of warranty returns become more uncertain than those products with a short-term warranty period. For example, new failure modes not present in the early phases show up in the warranty scope and have to be considered for an accurate estimate of cost.

2.2 Assumption of the reliability model

The concepts of inherent reliability and field reliability should be distinguished, as many authors have already noticed, say (Murthy, Rausand & Østerås 2008) and Figure 1, for example. Inherent reliability is the reliability of a product before the product is shipped out for sale, whereas field reliability is the reliability that is estimated from data collected from the field.

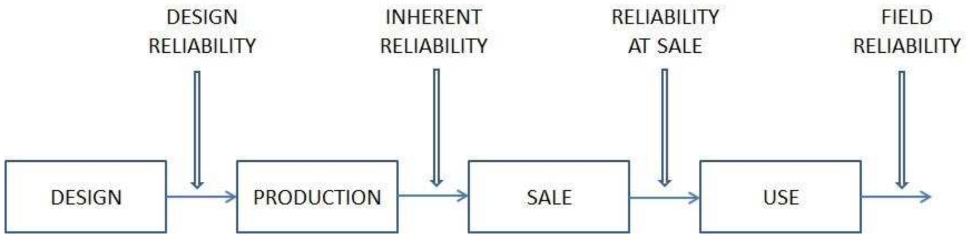

Figure 1. Reliabilities (adapted from {{395 Murthy, DN Prabhakar 2008}}

It should be noted that the field reliability of a product may be significantly different due to its operating environments. For example, a product may have a shorter lifetime in a server weather condition than in a mild weather condition. In particular, situations where the specifications of the product are exceeded ("over-stress") have a significant impact on the life expectancy of an individual unit. The difference of the inherent reliability of a product may not have such a significant variation. That is, in many cases, to estimate field reliability is not easy.

To optimise the warranty policy for a product, one needs to know the reliability of the product. Normally, warranty policy is optimised before the product is shipped out to its retailers and then used in the field. As a result, optimisation of warranty policies based on inherent reliability may lead to biased results. This is because that many factors influence on warranty claims, as shown in Figure 2 and also more detailed explanation in the following.

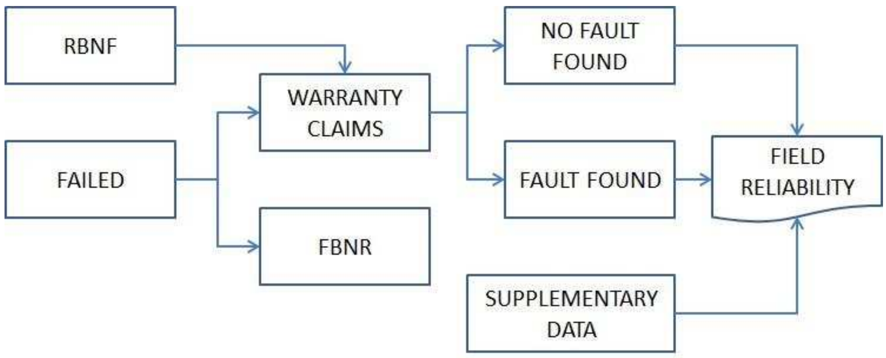

Figure 2. Warranty claim process (RBNF=Reported But Not Failed; FBNR=Failed But Not Reported)

2.2.1 Missing data: Failed But Not Reported (FBNR)

Nowadays, technical systems may also be seen a system composed of users, software systems and hardware systems. It should be noted that product users (e.g., mobile phone users) may not be bothered to claim warranty even if the items are still under warranty coverage due to various reasons. For example, the users might have purchased new and more advanced products (e.g., from Apple iPhone 4 to Apple iPhone 6) or they might find the effort of claiming warranty too high when compared to the price of the product. This causes a problem of FBNR (failed but not reported). Although there are some research papers attempting to optimise warranty policies with a consideration of FBNR, research on how the field reliability of a product with the existence of FBNR can be estimated is needed. One may of course assume some forms of FBNR functions of time, for example, (Patankar 1996) proposes 4 warranty execution functions. Unfortunately, there are not many research publications which show that those forms of warranty execution functions have been validated with real data, even with data collected from a questionnaire survey. This implies that an extra caution is needed in use of those warranty execution functions.

2.2.2 Unknown failures: no-fault found and Report But Not Failed

Brombacher showed that the observed categories of reliability problems were distributed as: components 21%; customers 17%, apparatus 24% and no fault found 38% (Brombacher 1999). On these statistics, the author further interpreted that the reliability failures in products were split into problems on a component level, problems on "internal product level" (e.g. interaction problems) and problems on a customer/application level. This analysis showed the largest single group where the cause of the failure remained unknown, or no-fault-found (NFF). The NFF phenomenon is a huge challenge when multipart products are dealt with. For example, the NFF contributes on average to 45% of reported service faults in electronic products (Jones, Hayes 2001). The problem is not new, but many believe it is getting worse, in part because today's highly complex products are equipped with more and more electronic sensors, computers, control functions and wires (Ramsey 2005). Furthermore, for cheap electronic products, the cost of performing a root cause analysis is significantly higher than the worth of the product and thus not regularly performed. This means that the causes of many warranty claims may not been identified and verified.

On the other hand, it has been reported that many claims are fraudulent. This causes another problem of NFBR (not failed but reported). To identify the NFBR phenomenon involves the ability of distinguishing between NFBR and other phenomenon, which may be due to manufacturing problems.

Due to the existence of the NFF and NFBR and their high frequency of occurrence, accurately estimating field reliability becomes a challenge.

2.2.3 Life cycle of a typical product

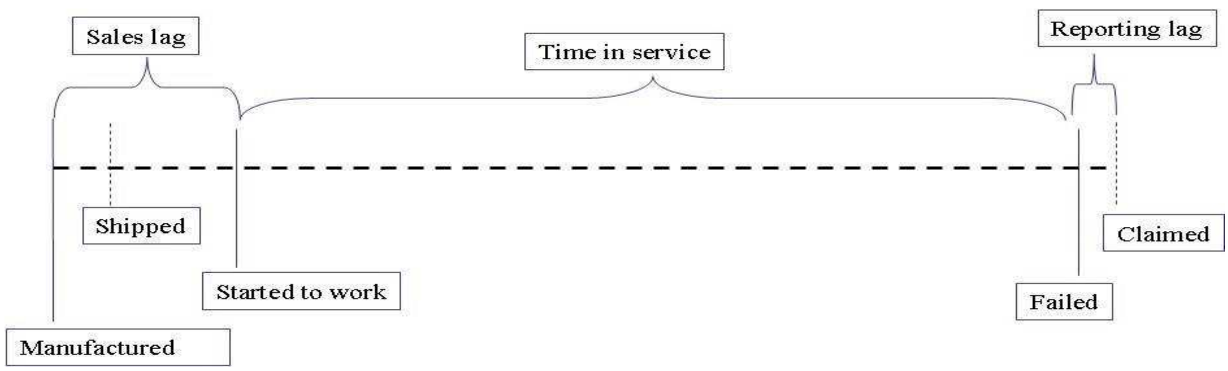

Figure 3. The life cycle of a typical product

The duration of lifetime warranties is defined in the warranty policy with conditions. In general, the term of lifetime is specified by manufacturer as the design life of the product or market life of the product.

Figure 3 shows a typical process from products being manufactured to failed products being received by a manufacturer. The products might be temporarily stored in a warehouse for a time period before they are shipped to distributors or partners or retailers, where the products might spend some time before they are purchased and put in use by users. That is, we can divide the whole period into the following four phases.

- Phase 1 --- This stage starts from the time when the products are manufactured until the time when the products are shipped to warehouses. In this phase, the products are still not shipped to distributors/ partners/retails.
- Phase 2 --- This stage starts from the time when the products are shipped to distributors/ partners/retails until the time when they are put in use. There can be several tiers of distributors/ partners/retails.
- Phase 3 --- This stage is the period when the products are operated.
- Phase 4 --- Stage 4 starts from the time when products fail until the time the manufacturer has received warranty claims.

Phase 1 and Phase 2 constitute a period of time called sales lag and Phase 4 is also called reporting lag (see Figure 3. From a reliability analysis perspective, only time in service, or time to failure (TTF), i.e. the time period of Phase 3, is needed but usually it may be difficult to collect the exact time length of Phase 3 because of sales lags and reporting lags may not precisely recorded (See Gitzel et al., 2015, for example).

2.2.4 Design modification and product obsolesce

Due to the competitive nature of the consumer market and customers' demands, manufacturers have started to provide warranties with relatively long period at the beginning of the 21st Century. There are increasing numbers of electrical and electronic product manufacturer who even sell their products with lifetime warranties and some automobile companies have also announced to sell cars with lifetime warranties. Lifetime warranty may persuade customers to buy the products because of its additional assurance which may influence the buyers' intension by convincing them that the products are reliable and can last a long time. Manufacturers who offer lifetime warranty for their products are trying to send the message that they are proud of their products and the customers who bought these products can have a peace of mind for as long as they will keep on using the products. In addition to the difficulty of estimating the cost of lifetime warranty due to the indefinite nature of product lifetime and its service conditions, the manufacturers may also modify product designs and declare products obsolete after they have been in the market for a time period.

Rapid technological advances in many industries, especially in the electronics manufacturing industry, make products obsolete quicker than before, which requires product manufacturers to provide long-term warranties to protect consumers' profits. After products have been declared obsolete, they will no longer be produced. This results in additional complexities as the uncertainties associated with costs incurred by such warranty servicing become more difficult to predict. For example, it is unclear if certain parts or even technologies will be available in the future and if stocked parts will survive storage long enough to the used. Furthermore, the skills required to work with the obsolete product might be lost due to retirements and personnel fluctuation driving up the required person hours and person hour cost. Also, completely new failure modes might occur as materials start to deteriorate in ways not normally considered. All this poses a challenge on optimising warranty servicing policy.

For example, Figure 4 shows the number of warranty claims that had been received. In month 28, a major modification on the product was conducted. As a result, the number of warranty claims became increasing. Of cause, a product modification does not necessarily mean that the reliability of the product is also been improved. Such modifications can be from a function perspective. In month 73, the product was announced obsolete. Following that, warranty claims become fewer. For such products, to obtain a precise estimate of the number of warranty claims, or further to estimate the reliability of the products on the basis of warranty claims, is extremely difficult due to the uncertainty presented.

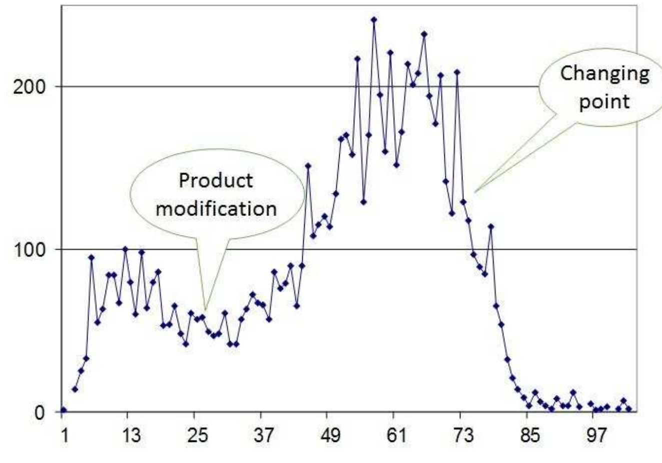

Figure 4. The number of warranty claims of a networking product.

2.3 Assumption on the relationship between age and usage

It can be found that a linear relationship between the age and the accumulated usage of a product ("running hours") is assumed by many authors. Optimisation of two-dimensional warranty policies needs first to understand the relationship between age and usage (see (Ye et al. 2013)). It should be noted, however, such an assumption may not hold due to the asymmetry existing between the two age and usage. Items with older age may have lower accumulated usage, but items with higher accumulated usage normally have older age (see Wu, 2014). Also, emergency equipment (such as an electrical motor used for emergency shutdown) or spare units might be quite old without having experienced a lot of actual use. As such, the linearity assumption of the relationship between age and usage needs validation before it is made.

2.4 Assumptions on modelling times between claims

In the literature, many reliability datasets have been published. Those datasets normally include data of time-between-failures. However, most of them do not indicate the failure modes, which may cause the problem that survival distributions are estimated based on time-between-failures due to failures of completely different components. Some publications do not check the statistical properties before they estimate models based on different assumptions. For example, a series of time-between-failure data are statistically independent, based on which a non-homogeneous Poisson process is estimated. On the other hand, when a series of time-between-failures are statistically dependent, but based on the data a renewal process or a geometric process is developed. In our experience, this is especially problematic in the case of repairable systems. It is highly problematic to collect the Time Between Failures (TBF) for failures that have nothing to do with each other such as a mechanical and an electronics failure in a robot and consider the robot as good as new afterwards.

2.5 Warranty policies for complex systems

Nowadays, technical systems become increasingly complex. They may be composed of software systems (e.g., embedded software systems for controlling their host hardware systems) and hardware systems. Authors normally suppose that the software and hard systems are structured in series, based on which warranty policies are derived. As a result, they have little difference with those derived on the assumption of single hardware systems. While such an assumption may be correct for some systems, it does not hold in many systems. The failure mechanism of software is different from that of hardware in that software failures are almost exclusively design problems. To make things worse, software tends to evolve over time due to updates, so it is hard to compare units of a system running different versions of the software (and having updated at different points in time). Normally, software systems have different warranty periods with hardware ones and their maintenance mechanisms are also different. As such, there is a need to study warranty management for such complex systems so that optimal warranty policies can be sought.

3. A real-world example

Table 1 shows the time between warranty claims of 22 subsystems of the same type of a product. Some users hope to sign extended warranty contract, which requires the manufacturer to optimise the price and duration of the extended warranty. The failure modes recorded in the warranty claims and maintenance log are on subsystem levels. The cost of repair on the claimed items is not free of noise as the costs on the same failure mode in some cases differ significantly. This suggests that it is unrealistic to derive a precise solution through optimising the expected cost, as normally did in many publications. Apparently, this is a typical example of optimisation of warranty policy for complex systems,

We have tried to fit the data with the renewal process, the geometric process, the non-homogeneous process with the power law (NHPP), and the virtual age process. Based on the AIC values of the processes, the NHPP-PL is selected. The expected number of failures in the first t hours is $\left(\frac{t}{239.299}\right)^{1.238}$. Given that the product has already survived for u time units, then the expected number of failures within next v time units is $\left(\frac{u+v}{239.299}\right)^{1.238}-\left(\frac{u}{239.299}\right)^{1.238}$. More importantly, a confidence interval of this estimated number of failures should be given in order to allow for the decision makers to understand the uncertainty associated with this expected number when they determine the duration of extended warranty and further price it.

Of course, one may also use the compound Poisson process to model the claim process, with which the uncertainties in both models of time-between-claims and cost on the claims are considered.

Table 1. Times between warranty claims (in day) (where x_1 is the time to first claim, x_k are times between the $(k-1)$th and the kth claims, where $k = 2,3$.)

No.	x_1	x_2	x_3	No.	x_1	x_2	x_3	No.	x_1	x_2	x_3	No.	x_1	x_2	x_3
1	142	56	35	7	530	59	266	13	46	93	41	19	97	41	413
2	201	259	21	8	14	403	223	14	448	45	9	20	436	795	207
3	206	281	29	9	314	15	176	15	378	169	261	21	648	22	175
4	26	195	423	10	60	9	28	16	270	16	103	22	315	231	54
5	251	461	117	11	117	26	156	17	301	38	45				
6	74	269	552	12	146	127	62	18	304	32	42				

4. Conclusion

This paper discussed main challenges in optimisation of warranty policies. Those challenges are mainly due to the reliability and validity of data collected from warranty claims and assumptions needed in warranty policy optimisation.

From the above discussion, it can be seen that there are many sources of uncertainty existing in the process of optimisation of warranty policy. To reduce the uncertainty and mitigate the risk of unbiased decision making, we suggest that more research attention should be paid on novel methods of dealing with risk and uncertainties in warranty policy optimisation. For example, more studies on risk based decision making methods in warranty optimisation are therefore needed.

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