# End-of-Life Product Warranty

Ammar Y. Alqahtani[1] and Surendra M. Gupta[2]*,
[1]King Abdulaziz University, Department of Industrial Engineering, Faculty of Engineering, Jeddah, 22254 SAUDI ARABIA,
[2]Northeastern University, Department of Mechanical and Industrial Engineering, 334 Snell Engineering Center, 360 Huntington Avenue, Boston, Massachusetts 02115 U.S.A.,
(617)-373-4846, gupta@neu.edu
(*corresponding author)

**Abstract**
This paper presents a warranty cost analysis for an Advanced Repair-To-Order, Disassembly-To-Order, Refurbishment-To-Order and remanufacturing-To-Order system for Sensor-embedded products (SEPs). The goal of the proposed approach is to introduce the idea of providing a warranty period for an end-of-life (EOL) product and how to predict a warranty period for the disassembled components using the sensor information about the age and usage of each and every EOL product on hand to meet product, component and recycled material demands while minimizing the cost associated with warranty and maximizing manufacturer's profit. A simulation model is proposed to optimize the system and predict, using the sensor information, the warranty period that should be assigned to each and every disassembled component and remanufactured product.

**Keywords:** Reverse Supply Chain, Simulation, Warranty, Remanufacturing

## Introduction and Related Work

Recently, the number of studies dealing with the end-of-life (EOL) stage of a product has gained a lot of attention from researchers (Gungor and Gupta 1999), (Ilgin, and Gupta 2010b). This is due, on one hand, to environmental factors, government regulations and public demands, and on the other hand, to potential economical profits that could be obtained by implementing reverse logistics and product recycling resolutions. Manufacturers try to cope with consumer awareness towards environmental issues and stricter environmental legislation by setting up facilities which involve the minimization of the amount of waste sent to landfills by recovering materials and components from returned or EOL products (Gungor and Gupta 2002).

In product recovery, the disassembly process plays an important role since it allows for selective separation of desired parts and materials. EOL products containing missing and/or nonfunctional components increase the uncertainty associated with the disassembly yield. Sensor-embedded products (SEPs) eliminate a majority of uncertainties involved with EOL management by providing life-cycle information (Gupta and Lambert 2008), (Vadde et al. 2008). This includes information about the content of each product and component conditions, that enables the estimation of remaining useful life of the components. Once the data about the product is captured, it is possible to make optimal EOL decisions without any preliminary disassembly or inspection operations (Ilgin, and Gupta 2010a, 2010b, 2010c, 2011). Once the components are retrieved, the products can be remanufactured.

The quality of a remanufactured product is still uncertain for consumers. Therefore, the consumers are unsure if the remanufactured products will render the expected performance. This ambiguity about a remanufactured product could lead the consumer to decide against buying it. With such apprehension held by consumers, remanufacturers often seek market mechanisms that provide assurance about the durability of the products. One strategy that the remanufacturers often use is to offer warranties on their products (Murthy and Blischke 2006).

Product warranties have three key roles. The first role is insurance and protection, allowing consumers to transfer the risk of product failure to sellers (Heal 1977). Next, product warranties can also signal product reliability to customers (Balachander 2001), (Gal-Or 1989), (Soberman 2003), (Spence 1977). Lastly, the sellers use warranties to extract additional profitability (Lutz and Padmanabhan 1995). There are a few articles and books that consider warranty policies for new products' supply chain management. However, there are none that consider the warranty for the remanufactured products' reverse and closed loop supply chain management (Blischke 1993, 1995, 2011).

## System Description

The Advanced Repair-To-Order, Disassembly-To-Order, Refurbishment-To-Order and remanufacturing-To-Order (ARTODTORTO) system deliberated in this study is a product recovery system. A sensor embedded air conditioner (AC) is considered here as an example product. Based on the condition of EOL AC, it will go through a series of recovery operations similar to the one shown in figure 1. Refurbishing and Repairing processes may require reusable components to meet the demand of the product. This requirement satisfies the internal and the external component demand. Both will be satisfied using disassembly of recovered components.

EOL ACs arrive at the ARTODTORTO system for information retrieval using radio frequency data reader which are stored in the facility's database. Then the ACs go through a six-station disassembly line. Complete disassembly is performed to extract every single component. There are nine components in an AC consisting of, evaporator, control box, blower, air guide, motor, condenser, fan, protector, and compressor. Exponential distributions are used to generate the disassembly times at each station, interarrival times of each component's demand, and interarrivel times of EOL AC. All EOLPs after retrieval of the information are shipped either to station 1 for disassembly or, if EOLP needs only repair for specific component, to the corresponding station. Two different types of disassembly operations, viz., destructive or nondestructive, are used depending on the component's condition. If the disassembled component is nonfunctional (broken, zero remaining life), then destructive disassembly is used such that the other components' functionality will not be damaged. Therefore, unit disassembly cost for a functional component is higher than nonfunctional component. After disassembly there is no need for component testing due to the availability of information on components' conditions from sensors. It is assumed that the demands and life cycle information for EOLPs are known. It is also assumed that retrieval of information from sensors costs less than actual inspection and testing.

Recovery operations differ for each SEP based on its condition and estimated remaining life. Recovered components are used to meet components and spare parts demands, while recovered or refurbished products are used for product demands. Also, material demands are met using recycled products and components. Recovered products, and components are characterized based on their remaining life times and are placed in different life-bins (e.g. 1 year, 2 years, etc.) waiting to be retrieved via a customer demand. Underutilization of any product or component could happen when it is qualified for a higher life-bin and is placed in a lower life bin because the higher life bin is full. Any product, component or material inventory which is greater than the maximum inventory allowed is assumed to be extra and is used for material demand or disposed of.

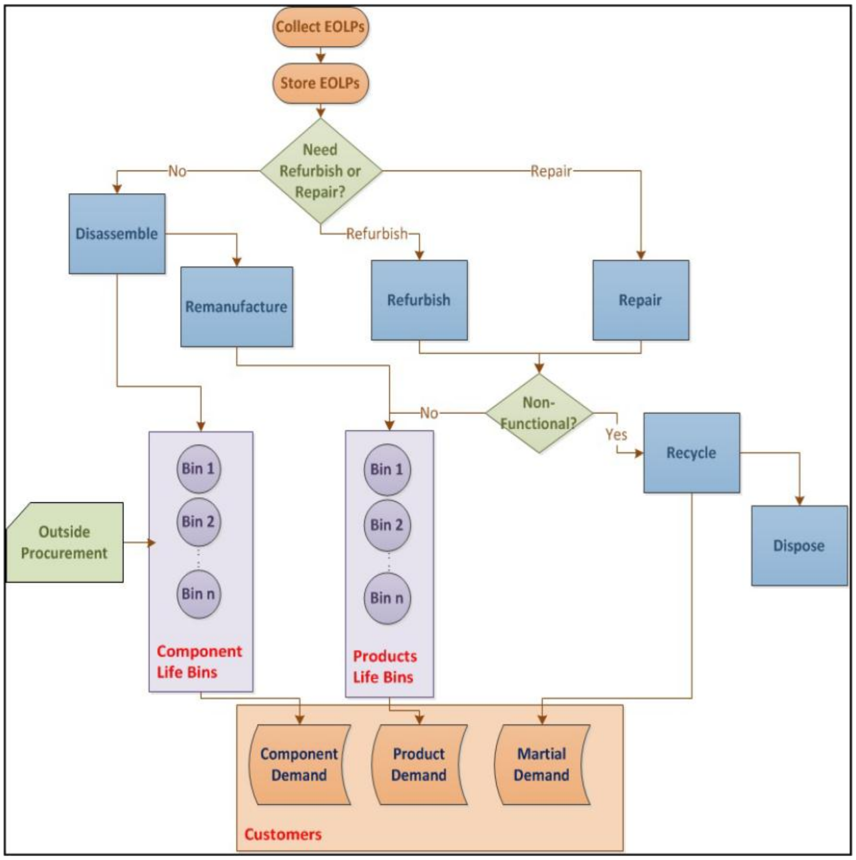


*Figure 1: ARTODTORTO System's recovery processes*

In order to meet the product demand, repair and refurbish options could also be chosen. EOLP may have missing or nonfunctional (broken, zero remaining life) components that need to be replaced or replenished during the repairing or refurbishing process to meet certain remaining life requirement. EOLP may also consist of components having lesser remaining lives than desired, and for that reason might have to be replaced.

## Warranty Cost Analysis

In the process of deciding to purchase merchandise, the buyers usually compare features of a product with other competing brands that are selling the same product. In some cases the competing brands make similar products to each other with similar features such as cost, special characteristics, quality and credibility of the product and even insurance from provider. In these cases after sale factors come in effect such as discount, warranty, availability of parts, repairs and other additional services. These factors will be very significant to the buyer in such situation and specially the warranty since it further assures the buyer of the reliability of the product.

A warranty is an agreement that requires the manufacturer to correct any product failures or compensate the buyer for any problems that occurs with the product during the warranty period in relevance to its sale. The objective of the warranty is to promote the products quality and guarantee its performance in order to assure production for both the manufacturer and the buyer.

There are many different available warrantee polices which most products are sold with. The most famous used consumer warranty is the basic Free Replacement Warrantee (FRW). The basic FRW is the warranty is a reference to price and it relies on many factors, the main expense of the warranty is the price of the product plus the servicing of an item that fails during the warranty period. The warranty cost is the expense of servicing all warranty claims for a product during the overall period of the warranty.

## Notation and Warranty Cost Formulation

The nomenclature used in this paper is given below:

*L* Life cycle (remaining life)
*W* Length of warranty period
*Cs* Cost of the manufacturer of supplying a remanufactured item
*Cp* Sales price per unit
*Cr* Average cost of each repair
*MTTF* Mean time to failure
$\alpha$ Weibull distribution shape parameter, $0 \leq \alpha \leq 1$
*M(W)* Average number of replacement during the warrant period *W*

The expected warranty cost could be calculated using Blischke and Murthy (1994) formula as follows:

$$\text{Expected warranty cost} = Cs \,.\, [\, 1 + M(W)] \quad (1)$$

## Numerical Example

The example considers FRW policy for the remanufactured AC's components and products with three different remaining lives (1 year, 2 years and 3 years) and three different warranty periods (30 days, 60 days and 90 days). Suppose the mean time to failure of the AC is *MTTF* = 20 days, the other data used for implementation of the model are shown in table 1:

*Table 1 Operation costs (disassembly, assembly), sale price and repair cost for AC components*

| Components | *Cs* = Operation costs ($/unit) | *Cp* = Sale Price ($/unit) | | | *Cr* = Repair costs ($/unit) |
|---|---|---|---|---|---|
| | | *L* = 1 Year | *L* = 2 Years | *L* = 3 Years | |
| Evaporator | $4.00 | $10 | $15 | $35 | $8.00 |
| Control Box | $4.00 | $20 | $30 | $15 | $8.00 |
| Blower | $2.80 | $5 | $12 | $15 | $5.60 |
| Air Guide | $1.20 | $5 | $12 | $60 | $2.40 |
| Motor | $4.00 | $45 | $55 | $25 | $8.00 |
| Condenser | $1.66 | $15 | $18 | $20 | $3.32 |
| Fan | $2.34 | $15 | $18 | $20 | $4.68 |
| Protector | $0.60 | $15 | $20 | $65 | $1.20 |
| Compressor | $3.40 | $50 | $60 | $35 | $6.80 |
| AC | $55.00 | $180 | $240 | $310 | $85.00 |

## Results

The total expected to the remanufacturer under the above assumptions are given in table 2 for $W$ = 30, 60, and 90 days. These costs are the average total cost associated with supplying the initial item and all necessary replacements for items that fail under warranty.

In table 2, expected number of failures is the expected number of failed items per unit sale, in other words is the average number of free replacements that the remanufacturer would have to provide per unit sold during the warranty period. Expected cost to remanufacturer includes the cost of supplying the original item *Cs*. Accordingly, expected warranty costs alone are calculated as tabulated Expected cost to remanufacturer minus *Cs* for that item.

The results given in table 2 are useful in order to choose the length of an FRW warranty. From the table above it is obvious that the cost will increase if the length of the warranty period increases. However, except for $\alpha = 1$, this increase is not linear. For $\alpha > 1$, warranty cost increase at an increasing rate. The cost of warranty is dependent on the value of Weibull shape parameters $\alpha$. The worst case is when $\alpha = 1$, which corresponds to failures occurring at a constant rate. In this case warranty cost increases at a constant rate as will, and quickly become unacceptable large. For $W$ = 30 (a 30-days warranty on an item with an average time to failure of 20 days), the warranty cost for AC is $2.50 which is 4.5% of the cost of supplying an item Cs, but significantly less than that percentage of the selling price. This may be acceptable, but the corresponding values for longer warranties become excessive. For example the warranty of 90 days for AC will cost 40% of the cost of supplying the product.

## Conclusion

The warranty cost for remanufactured products and components was evaluated in this paper using the free replacement warranty policy for different periods. The main objective was to introduce the idea of providing a warranty period for an end-of-life (EOL) product and how to predict a warranty period for the disassembled components using the sensor information about the age and usage of each and every EOL product on hand to meet product, component and recycled material demands while minimizing the cost associated with warranty and maximizing manufacturer's profit. A simulation model was used to optimize the system and predict the warranty period that should be assigned to each and every disassembled component and remanufactured product.

*Table 2 Expected warranty costs for AC components and remanufactured AC*

| ***Components*** | ***W* (days)** | **Expected number of failures** | | | **Expected cost to remanufacturer** | | |
|---|---|---|---|---|---|---|---|
| | | **α = 1** | **α = 2** | **α = 3** | **α = 1** | **α = 2** | **α = 3** |
| Evaporator | **30** | 0.8330 | 0.0054 | 0.00041 | $4.50 | $5.16 | $4.12 |
| | **60** | 0.1670 | 0.0217 | 0.00329 | $5.00 | $5.65 | $4.20 |
| | **90** | 0.2500 | 0.0483 | 0.01107 | $7.50 | $7.45 | $4.33 |
| Control Box | **30** | 0.8230 | 0.0051 | 0.00040 | $4.42 | $5.13 | $4.11 |
| | **60** | 0.1770 | 0.0213 | 0.00327 | $5.21 | $5.50 | $4.17 |
| | **90** | 0.2400 | 0.0480 | 0.01103 | $7.41 | $7.31 | $4.30 |
| Blower | **30** | 0.8130 | 0.0050 | 0.00041 | $2.21 | $2.07 | $2.11 |
| | **60** | 0.1570 | 0.0218 | 0.00326 | $2.91 | $3.67 | $2.16 |
| | **90** | 0.2300 | 0.0488 | 0.01102 | $4.02 | $4.52 | $2.24 |
| Air Guide | **30** | 0.8130 | 0.0022 | 0.00043 | $1.22 | $1.19 | $1.02 |
| | **60** | 0.1170 | 0.0221 | 0.00322 | $1.76 | $1.62 | $1.12 |
| | **90** | 0.2100 | 0.0423 | 0.0111 | $2.33 | $2.31 | $1.19 |
| Motor | **30** | 0.7890 | 0.0051 | 0.00044 | $4.61 | $4.42 | $4.32 |
| | **60** | 0.1710 | 0.0212 | 0.00333 | $5.07 | $4.73 | $4.40 |
| | **90** | 0.2410 | 0.0488 | 0.01107 | $7.12 | $6.12 | $4.44 |
| Condenser | **30** | 0.8220 | 0.0055 | 0.00045 | $1.44 | $1.23 | $1.20 |
| | **60** | 0.1600 | 0.0216 | 0.00331 | $2.09 | $1.76 | $1.32 |
| | **90** | 0.2520 | 0.0487 | 0.01115 | $2.42 | $2.03 | $1.39 |
| Fan | **30** | 0.8420 | 0.0050 | 0.00042 | $2.76 | $2.33 | $2.24 |
| | **60** | 0.1840 | 0.0214 | 0.00328 | $3.81 | $2.73 | $2.30 |
| | **90** | 0.2420 | 0.0484 | 0.01113 | $4.74 | $3.79 | $2.42 |
| Protector | **30** | 0.8500 | 0.0054 | 0.00040 | $0.73 | $0.57 | $0.41 |
| | **60** | 0.1570 | 0.0215 | 0.00320 | $1.13 | $0.92 | $0.49 |
| | **90** | 0.2390 | 0.0488 | 0.01109 | $1.98 | $1.33 | $0.53 |
| Compressor | **30** | 0.8210 | 0.0054 | 0.00049 | $3.20 | $3.00 | $2.87 |
| | **60** | 0.1660 | 0.0216 | 0.00327 | $4.12 | $3.87 | $3.11 |
| | **90** | 0.2410 | 0.0485 | 0.01105 | $5.61 | $5.07 | $3.21 |
| AC | **30** | 0.8120 | 0.0054 | 0.00046 | $57.50 | $55.16 | $54.64 |
| | **60** | 0.1900 | 0.0218 | 0.00339 | $60.00 | $60.65 | $57.20 |
| | **90** | 0.2490 | 0.0485 | 0.01102 | $70.50 | $69.45 | $59.33 |

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