

Lessons in System Reliability

FROM THE QUANTERION *SYSTEM RELIABILITY TOOLKIT-V*



The important topics included in this short publication are shared here from the popular Quanterion Solutions' 900+ page System Reliability Toolkit-V. Please give us a call if you need help in any reliability engineering need (315-732-0097).

This edition includes one Toolkit topic, which is Topic 1.8: Warranties.

Topic 1.8: Warranties

Warranties exist in both the government and commercial marketplace and are very similar in nature. They identify the item that is warranted, the length of the warranty, what is covered by the warranty, acceptable use conditions of the warranted item, and the warrantor's liability. Four basic principles apply to both government and commercial warranties:

- Warranties are not free
- Warranted items fail
- Warranties do not ensure the quality of performance
- Warranties define the level of quality or performance for which a warrantor is willing to accept liability

Commercial manufacturers include the cost of a warranty in the sale price of the warranted item prior to sale. There are basically two distinct product areas that commercial warranties address, commercial and consumer products. A consumer

product is a commercially distributed item normally used for personal, family or household purposes. Commercial products may be defined as goods sold between merchants. They generally fall under federal and state domains: the Magnuson-Moss Federal Trade Commission Improvement Act and the Uniform Commercial Code. Commercial product warranties are covered by the Uniform Commercial Code of each state. The requirements surrounding commercial warranties are governed by law and are influenced more by competition than consumer/commercial mandates. Though it is impossible to list all of the laws associated with warranties in this Toolkit, Table 1.8-1 provides a summary of some key points.

Generally, there are two types of "commercial" warranties, expressed and implied. An expressed warranty is any statement, written or oral, that is made about the product through brochures, advertisements or salesperson's claims. An implied warranty ensures that an item is merchantable (the goods will pass without objection in the trade) and it will perform the function it claims.

Several types of commercial warranty policies exist that are used to document liabilities of the buyer and seller. Table 1.8-2 summarizes the particulars of some typical commercial warranty policies, while Table 1.8-3 provides more detail.

Military suppliers used to be governed by government laws to adhere to a strict set of requirements when developing government

WARRANTIES

Table 1.8-1: Commercial and Consumer Warranty Law

Factor	Definition	Description
Coverage	Commercial products	Goods sold between merchants. If greater than 10 to 20% of the product sales are to consumers then the product is classified as a consumer product.
	Consumer products	Commercially distributed products
Warrantor	Spelled out in the written warranty	Party that assumes responsibility for the warranty
Warranties	Commercial warranty	Governed by the Uniform Commercial Code of each state. Implied warranties can be canceled in the written warranty. Refunds do not have to be offered for defective products.
	Full consumer warranty	No restrictions on implied warranties. Also, solutions to claims within a reasonable time at no charge must be provided or the purchase price less depreciation must be refunded when an item cannot be repaired within a reasonable number of attempts.
	Limited consumer warranty	Does not meet all restrictions of a full warranty and it is not required that refunds be offered. The implied warranty can only be restricted to the same length of time as the written warranty.
Exclusions	All exclusions must be spelled out in the written warranty	Peripherals, consumables, parts covered by other warranties Equipment not operated under normal conditions Equipment not operated or maintained in accordance with furnished manuals

Table 1.8-2: Commercial Warranty Policies

Warranty Policy	Definition	Description
Free Replacement Warranty	Seller pays the entire cost of the remedy if the product fails before the end of the warranted period. Remedied item has a warranty equal to the remaining length of the original item.	Favors the buyer at the expense of the seller
Unlimited Free Replacement Policy	Seller pays the entire cost of the remedy if the product fails before the end of the warranted period. Remedied item has a warranty identical to the warranty of the original item.	Typically used for small electronic appliances that fail as a result of infant mortality. Favors the buyer at the expense of the seller.
Pro-Rata Warranty Policy	If a product fails before the end of a warranty period, it is replaced at a cost which depends on the age of the item or the remaining life (i.e., remaining tire tread depth) at the time of failure. The replacement item typically carries a warranty identical to that of the original.	Typically used on wearout items. Since a buyer may have to purchase a new item at some cost should an earlier warranted item fail, the warranty favors the seller at the expense of the buyer.
Combination Policy	Contains both free and pro-rata periods	Has promotional appeal to attract buyers and keeps the warranty cost to the seller at a reasonable amount
Fleet Warranty	Covers a population of items. The manufacturer guarantees that the mean life of a population of items will meet or exceed a negotiated mean regardless if individual items have short lifetimes.	Typically used when a large number of items are sold to a common buyer and replacement parts are supplied by the manufacturer

warranties, but the process is now more ad hoc and not defined by policy. The Defense Procurement Reform Act (Public Law 98-525), effective January 1985, established Title 10, Section 2403, of the United States Code, entitled "Major Weapon Systems: Contractor Guarantees" was repealed in November 1997. The contractor would typically have to evaluate the cost and risk of implementing a warranty and submit and negotiate this estimate with the government. The law required that the prime contractor for a production weapon system provide written guarantees regarding design/manufacturing requirements, defects in materials/

workmanship, and essential performance requirements (the DoD uses the terms "guarantee" and "warranty" interchangeably) for weapon system procurements. The cost of a warranty for government products is typically not included in the cost of the item. Since being repealed, government warranties may still be imposed, but their use is more ad hoc and lacking in firm policy direction. Nondevelopmental items (NDI) and "non-weapon" systems can still be procured with commercial warranties. Table 1.8-4 summarizes the essential features of that law.

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Table 1.8-3: Detailed Warranty Descriptions

Name	Description
Free-Replacement Policy (FRW)	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period
Rebate FRW	Seller agrees to refund a portion of the selling price for failure prior to the end of the warranty period (technically not an FRW)
Rebate FRW (also referred to as "money-back guarantee")	Seller agrees to refund the purchase price if item fails prior to end of the warranty period
Pro-rata Rebate Policy (PRW)	Seller refunds a fraction of the purchase price if failure before the end of the warranty period. (Refund is a function of the time or usage and the buyer need not use the refund to buy another item)
Linear PRW	Seller agrees to refund which is a linear function of time up to the end of the warranty period
Proportional Linear PRW	Seller agrees to refund which is a proportional linear function of time up to the end of the warranty period
Nonlinear PRW	Seller agrees to refund which is a nonlinear function of time up to the end of the warranty period
Combination FRW/PRW	Seller repairs or provides replacements for failed items free of charge for a limited time (W1); seller provides a pro-rated refund for failures between that limited time and the end of the warranty period (W), where $W > W1$
Three-stage Warranty	Seller repairs or provides replacements for failed items free of charge for a limited time (W1); provides them at a certain cost (C1) for item failures between W1 and an extended time (W2); and provides them at a different cost (C2) for item failures between W2 and the end of the warranty period (W), where $W > W2 > W1$ and $C2 > C1$
Multistage Rebate Warranty	Seller repairs or provides replacements for failed items free of charge for a limited time (W1); provides them at a linear portion of the purchase price (a*C) for item failures between W1 and an extended time (W2); provides them at linear portion of the purchase price (b*C) for failures between W2 and a further extended time (W3); and provides them at linear portions (c*C, d*C, e*D,...) of the purchase price (a<b<c<..... and $W1 < W2 < W3 < \dots < W$ up to the end of the warranty period
Combination Lump-sum Rebate Warranty	Seller provides a rebate (a*C) for failure prior to a limited time (W1), a rebate (b*C) for failure from W1 to an extended time (W2), a rebate (c*C) for failure from W2 to a further extended time (W3), and so on for periods up to the end of the warranty period. (a>b>c>..... and $W1 < W2 < W3 < \dots < W$)
Rebate Combination FRW/PRW	Seller provides a full refund of the price for a failure up to a limited time (W1); from W1 to the end of the warranty period, the seller provides a pro-rata refund. ($W > W1$)
Warranty with Storage Limitations	Seller provides a FRW, a PRW, or a mixed coverage similar to other types subject to a storage period (w), and an operating period (W), such that the coverage storage time is less than "w" and storage plus operating time is less than "W"
Renewing FRW	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period. Item provided as replacement carries warranty with identical terms to the original one.
Renewing PRW	Seller provides a replacement item at pro-rated cost for any failed items (original and any replacements) that fail before the end of the warranty period (proration can be various types). The buyer doesn't have the option to take a rebate.
Fully Renewing FRW/PRW	Seller provides a replacement for failures up to a limited time (W1); from W1 to the end of the warranty period, the replacement is at a pro-rated (various types of proration) cost. The replacement item carries the same warranty as the original item.
Partially Renewing Combination FRW/PRW: Renew in Pro-rated Period	Seller provides a replacement for failures up to a limited time (W1); replacement items assume the remaining portion of the original item's warranty. Failed items in the period from W1 to the end of the warranty period are replaced at the pro-rated cost with the new item warranty coverage the same as the original item.
Partially Renewing Combination FRW/PRW: Pro-rated Warranty in Pro-rated Period	Seller provides a replacement for failures up to a limited time (W1) with the replacement item having a warranty the same as the original item. Failed items during the period W1 to the end of the warranty period (W) are replaced at pro-rated cost and carry a pro-rated warranty up to time "W" from the time of the last replacement.
Two Dimensional FRW: Time or Usage Criteria	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period (time), or warranty usage (e.g., miles), whichever comes first.
Two Dimensional FRW: Time and Usage Criteria	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period (time), or warranty usage (e.g., miles) whichever comes last.
Two Dimensional FRW: Time and Usage Limits	Seller repairs or provides replacements for failed items free of charge up to a limited time (W1), as long as usage is less than the warranty upper limit, and up to a limited usage limit as long as the time is less than the end of the warranty period
Two Dimensional FRW: Triangular Time and Usage Criteria	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period (W) and for a specific warranted usage (U). The warranty applies only if a plot of time (x) vs. usage (y) is within the region bounded by the line $y = -(U/W)x + U$ and the origin.

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Table 1.8-3: Detailed Warranty Descriptions, Continued

Name	Description
Two Dimensional FRW: Time and Usage Limits	Seller repairs or provides replacements for failed items free of charge up to a limited time (W1), as long as usage is less than the warranty upper limit, and up to a limited usage limit as long as the time is less than the end of the warranty period
Two Dimensional FRW: Triangular Time and Usage Criteria	Seller repairs or provides replacements for failed items free of charge up to the end of the warranty period (W) and for a specific warranted usage (U). The warranty applies only if a plot of time (x) vs. usage (y) is within the region bounded by the line $y=-(U/W)x+U$ and the origin.
Two Dimensional PRW: Time and Usage Price Fraction Refund	Seller refunds a portion of the price to the buyer for failures before the end of the warranty period and if the total usage less than that specified in the warranty.
Two Dimensional PRW: Time and Usage Product Refund	Seller refunds an amount of the price "C" equal to $((1-X/W)(1-Y/U)*C)$ to the buyer for failures before the end of the warranty period (W) and where the total usage is less than that specified in the warranty, where "X" is the actual time and "Y" is the actual usage when the failure occurred
Two Dimensional PRW: Minimum of Proportions Refund	Seller refunds an amount of the price "C" equal to $(\min[1-X/W; 1-Y/U]*C)$ to the buyer for failures before the end of the warranty period (W) and where the total usage is less than that specified in the warranty (U), where X is the actual time and Y is the actual usage.
Two Dimensional PRW: Product of Proportions Refund	Seller refunds an amount of the price "C" equal to $(1-XY/UW)*C$ to the buyer for failures before the end of the warranty period (W) and where the total usage less than that specified in the warranty (U), where X is the actual time and Y is the actual usage.
Two Dimension Combination FRW/PRW	Seller repairs or provides replacements for failed items free of charge up to a limited time (W1) provided the usage is less than a specified limit (U1); for any failure at time greater than W1 but less than the end of the warranty period and/or usage greater than U1 but less than the specified end-of-warranty usage, the unit is replaced at pro-rated cost.
Cumulative FRW: One-at-a-Time Item Use	Seller provides free replacement items, as long as the total service time is less than $LOT*W$ (where "LOT" is the number of items operating one at a time in the lot and "W" is the end of the warranty period time).
Cumulative FRW: Multiple Item Use	Seller provides free replacement items after a unit has failed, as long as the cumulative total service time is less than $LOT*W$ (where "LOT" is the number of items operating at a time in the lot and "W" is the end of the warranty period time).
Cumulative PRW: Refund at Last Failure	Seller provides buyer a refund equal to $(C*(LOT-S/W))$ if, after the failure of the last of the items in the lot (LOT), the cumulative total service time is less than $LOT*W$, where "W" is the end of the warranty period. The items can be used individually or in batches.
Cumulative PRW: Instantaneous Rebate	A lot of "LOT" items is warranted for a total time of $LOT*W$ ("W" = the end of the warranty period) where the lot is divided into subsets of size "K1". The seller provides an instantaneous refund to the buyer at the occurrence of the K^{th} failure of each subset equal to $\max(0, C*(K2-SL/W))$ where "C" is the cost of the item, "SL" is the sum of the service times of the "K1" failed items in the subset and "K2" is the number of subsets of items in the lot.
Cumulative Combination FRW/PRW	A lot of "LOT" items is warranted for a total time of $LOT*W$ ("W" = the end of the warranty period). Upon the failure of the final item in the lot, the total service time "SL" is calculated. If $SL < LOT*W1$ where "W1" is a limited time that is less than the end of the warranty period (W), free replacements are provided until $LOT*W1$ is achieved. Assuming that this criteria is achieved with "n+j" units, when the $(n+j)^{th}$ unit fails, the seller provides the buyer a rebate equal to $(\max[0; (LOT-SL/W)]*C)$, where "C" is the cost of the item. If $(LOT*W1*SL) < (LOT*W)$, the seller provides a rebate equal to $C*(LOT-SL/W)$.
Reliability Improvement Warranty: Item MTBF Guarantee	Seller repairs or provides replacements for any failed items until time W. Seller also guarantees that the MTBF of units is at least M. If the computed MTBF is less than M, the seller will provide (1) engineering analysis of the cause of failure to meet the MTBF guarantee, (2) engineering change proposals, (3) modifications of all existing units IAW approved engineering changes, and (4) consignment spares for the buyer until such time that the MTBF meets the requirement M.
Reliability Improvement Warranty: Multiple MTBF Guarantees	Seller repairs or provides replacements for any failed items until the end of the warranty period (W). Seller also guarantees that the MTBF of units (1) is not guaranteed up to a limited time "W1", (2) is guaranteed to be at least a certain MTBF (M1) for the period W1 to an extended time (W2), (3) is guaranteed to be at a certain higher MTBF (M2) for the period W2 to a further extended time (W3), and (4) is guaranteed to be at least a minimum MTBF (M3) for the period W3 to the end of the warranty period "W", where $W > W3 > W2 > W1$ and $M3 > M2 > M1$. If the guarantee is not met during any period, the seller will provide engineering changes and product modifications, as necessary, to meet the MTBF requirements.
Reliability Improvement Warranty: Number of Failures Threshold	A lot of "LOT" items is purchased with individual warranty periods of "W". Items that fail before the end of their individual warranty periods are repaired or replaced at the buyer's expense until a specified number of such failures occur, after which the seller will repair/replace failed items until each of the "LOT" items and their replacements achieve a total service time of "W".

WARRANTIES

Table 1.8-4: Repealed Government Warranty Law

Factor	Definition	Description
Coverage	Weapon systems	Used in combat missions; unit cost is greater than \$100,000, or total procurement exceeds \$10,000,000.
Warrantor	Prime contractor	Party that enters into direct agreement with U.S. to furnish part or all of weapon system
Warranties	Design and manufacturing requirements	Item meets structural and engineering plans and manufacturing particulars
	Defects in materials and workmanship	Item is free from such defects at the time it is delivered to the government
	Essential performance requirements	Operating capabilities or maintenance and reliability characteristics of item are necessary for fulfilling the military requirements
Exclusions	Government furnished property (GFP), Government furnished equipment (GFE), Government furnished material (GFM)	Items provided to the contractor by the government
Waivers	Necessary in the interest of national defense; warranty not cost-effective	Assistant Secretary of Defense or Assistant Secretary of the Military Department is lowest authority for granting waiver; prior notification to House and Senate committees required for major weapon system

A summary of commercial and past government warranty characteristics is provided in Table 1.8-5.

Table 1.8-5: Summary of Commercial and Government Warranties

Commercial	Military
Self determined requirements	Customer specified requirements
Extensive market research	No market research
Manufacture prior to sale	Manufacture after sale
Factory authorized service	Service performed by user
"Orderly" user environment	"Hectic" user environment

Warranties are beneficial to both the customer and manufacturer of a warranted product Incentives include the following:

Manufacturer

- Improves chance of future business
- Expands product market
- Improves chance for repeat business
- Cost controls established through product design, production and field support

User

- Decreases risk
- Calculable risk
- Improves cost versus profit ratio by lowering initial and operational costs
- State of the art advancement: reliability, maintainability, accuracy, operation and function

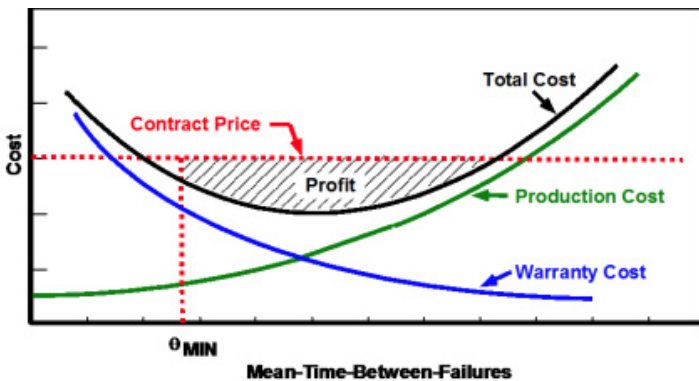
Competition and product liability provide constraints for the commercial supplier and consumer. Competition is one of the most significant drivers in consumer, and to some extent in commercial, warranties. The length of a warranty, the type of warranty, the degree of coverage and the thoroughness of remedies can be traded off by a seller when establishing a warranty. To determine the cost of the warranty, sophisticated analyses that determine the level of this increase must be performed. Suppliers often keep detailed records on the frequency and cost of service and use this data in the development of a warranty. When the warranty pertains to a new product, "what if" cost and risk analyses can be performed to determine the expected cost of proposed warranty options. Also, before a warranty is written, the seller must understand performance and serviceability issues of his product that are in tune with the customer marketplace.

Warranties may be used for either promotional purposes or for supplier protection. The warranty may improve sales or market share by differentiating a product from the competition (promotion), or limit supplier liabilities (protection). It should be noted that a poor warranty approach can negatively impact potential sales or cause the manufacturer to incur large remedial costs.

WARRANTIES

Reliability is a principal system performance parameter that government warranty law used to address. Reliability differs from quality in the sense that it pertains to the long-term performance of the system (i.e., its mean-time-between-failure). Reliability is a more elusive product attribute than quality: it cannot be measured easily, and it may not offer short-term motivation to a contractor. In fact, failures of a deployed system may mean more profit for a contractor if the contractor is also providing maintenance or spares. In addition, if reliability is a serious problem, the same contractor is probably tasked to develop a fix and to retrofit existing systems. Figure 1.8-1 illustrates contractor profit motivation with a warranty.

Figure 1.8-1: Contractor Profit Motivation



There are other motivations besides reliability that can be associated with a warranty. Being involved throughout the warranty period may cause the contractor to be concerned with maintenance, diagnostics, training, data and other logistics and support factors. As an example, warranties have been written under which a contractor is not reimbursed for processing good units returned unless the percentage of such return is very high. Since such processing is costly, the contractor may be motivated to improve the built-in test equipment, technical manuals, test equipment and other elements associated with failure detection and verification.

Another motivational factor concerns maintenance efficiency. If the contractor has to repair/fix all warranted failures, it is important that there be an efficient and effective repair/fix process. There have been a number of instances in which such warranties influenced the contractor to design for maintenance as well as reliability.

When the contractor views warranty as a potential profit source and a means for achieving a competitive edge, a number of positive motivational factors may be present. Producers of quality equipment need not add significant warranty contingency or risk funds to the price to cover future failures, and they need not spend all of their warranty funds to fix a poor product.

A number of warranty classification schemes have been developed to describe alternatives available to government procurement activities. The usual classification scheme distinguishes between assurance and incentive forms of warranties. Table 1.8-6 compares their basic characteristics.

Continued on the following page.



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WARRANTIES

Table 1.8-6: Comparison of Assurance and Incentive Types of Warranties

Factor	Assurance Warranty	Incentive Warranty
Basic Intent	Meet minimum performance and R&M levels	Exceed minimum levels
Warranty Price	Expected to be minimal, from 0 up to 1 or 2 percent per year of hardware price	May be significant, up to 7 or 8 percent per year of hardware price
Warranty Duration	Limited—generally 1 year or less	Can be extensive—3 or more years
Technology Factors	Warranted item is well within state-of-the-art (SOA), or SOA is so severely "pushed" that only limited warranty protection is realistic	Warranted item pushes SOA, so there is need to protect against failure and there is opportunity for growth
Contractor	Contractor has limited opportunity to control and improve performance prior to and during performance	Contractor has significant opportunity to control and improve warranty
Competition	Should not reduce future competitive climate	May significantly reduce competitive climate
Administration	Generally not a severe burden	May require complex procedures

Table 1.8-7 summarizes the four most common incentive forms of reliability-based warranties that have been used in the past by the government.

Table 1.8-7: Summary of Four Incentive Forms of Warranty

Incentive Warranty Form	Objective	Approach	Remedies	Application
Reliability Improvement Warranty (RIW)	Achieve acceptable reliability and motivate contractor to improve	Contractor performs depot maintenance for at least two years under fixed price	Contractor repairs/fixes all covered failures and has the option of implementing Engineering Change Proposals (ECPs) for R&M improvement	Units must be depot-repairable. Reduced military self-sufficiency must be tolerable.
Mean-Time-Between-Failures Guarantee (MTBFG)	Provide assurance that required MTBF level will be achieved	Contractor guarantees field MTBF. Measurements are made and compared with guaranteed value.	Contractor must develop and implement solution if guaranteed value is not achieved. Contractor may have to provide consignment spares in the interim.	MTBF is appropriate reliability parameter and field measurement can be made
Availability Guarantee (AG)	Provide assurance that required operational availability will be achieved	System availability is measured in the field or through a special test and compared to guaranteed values	Same as for MTBF guarantee	Availability is appropriate reliability parameter and field measurement can be made
Logistics Support Cost Guarantee (LSCG)	Control logistics support costs	Contractor "bids" target logistics support cost through use of a model. Field parameters are measured and the same model is used for obtaining measured logistics support costs and compared to target.	Contract price is adjusted based on actual versus target values; a correction of deficiency may be required.	Appropriate life cycle cost (LCC) model exists. Generally requires a special test program to obtain measured values.

For More Information:

"Reliability, Maintainability, and Supportability RMS Guidebook," Second Edition, Society of Automotive Engineers, 1992.

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Belvoir, VA, 1986.

Reid, S., D.N. Isaacson, and J.R. Brennan, "Warranty Cost-Risk Analysis," Annual Reliability and Maintainability Symposium Proceedings, 1991.

AFR 70-11, "Acquisition Management," Weapon Systems Warranties, 1988.

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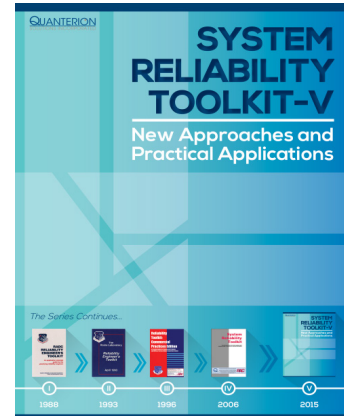
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The next article in the series is Topic 2.4.1: Software vs. Hardware Reliability, which explores the relationship between these two categories of reliability engineering.

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