Logistic support for the improvement of the warranty management

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ABSTRACT: Nowadays, providing a good post-purchase service has become extremely important then the efficiency of warranty management programs seems to be crucial. On these considerations, the paper deals with the problem of improving warranty management programs through logistic support planning. Starting from a reference framework for warranty management, the paper outlines the role that the logistic support can play in increasing process efficiency. In particular, different aspects are addressed, such as classification of system components, definition of repair levels and maintenance tasks. The presented framework is referred to the military industry in which logistic support strategies are widely applied. Despite this, proposed methodology can be considered universally valid and easily applicable to different contexts.

1 INTRODUCTION

As a result of the increasing customer expectations, product performances and characteristics are no longer the sole aspects to consider in a competitive global market. Nowadays, products must perform satisfactorily over their useful life to reach buyers satisfaction. In this context, the role of post-sale services, particularly during warranty period, becomes crucial so that an efficient warranty program represents a competitive weapon.

The management of warranty is not a simple issue as it combines technical, administrative and managerial actions. During the warranty period, an item must be maintained or restored to a state in which it can perform the required function, needed to provide a given service (Gonzalez Diaz et al. 2009). There are different types of warranties; each one suited a different type of product (consumer, commercial and industrial, standard versus custom-built, etc.) (Lyons & Murthy 2001, Menezes & Quelch 1990).

A literature review reveals important interactions between warranty and other disciplines (Gonzalez Diaz et al. 2009, Murthy & Djamaludin 2002, Murthy & Blishke 2005, Gonzalez Diaz & Crespo Marquez 2010, Murthy et al. 2004) impacting warranty efficiency. Among all of them, particularly important are the followings:

- Outsourcing: warranty service or in general, the after-sales department of a company, is usually one of the most susceptible to be outsourced due to its low risk and due also to the fact that, among other features, outsourcing provides legal insurance for such assistance services (Gomez et al. 2009).
- Quality: a reliability and quality improvement of the product has not only an advantageous and favorable impact in front of the client; it also highly reduces the expected warranty cost (Chukova & Hayakawa 2004, Lutz & Padmanabhan 1998).
- Costs: in reference to cost estimation, there are nowadays methods to estimate accurately the final cost of a specific acquisition contract as, for instance, the “Estimate at Completion” (EAC) method (Christensen 1993), a management technique that can be used in a project for the control of the costs progress. Considering commercial products, many warranty cost estimation methods have been developed in recent years (Chattopadhyay & Murthy 2000, Nguyen & Murthy 2006, Samath-Paç & Taner 2008, Chattopadhyay & Rahman 2008)
- Maintenance: in many cases, during the warranty period the manufacturer still has a strong control over its product and its behavior. Additionally, the expected warranty costs depend normally not only on warranty requirements, but also on the associated maintenance schedule of the product (Yeh & Lo 2001, Dimitrov et al. 2004, Kim et al. 2004, Wu & Li 2007).
Considering the above mentioned aspects, main problems in warranty management efficiency seem to be correlated to logistic issues. One of the most critical warranty servicing process is in fact spare parts provisioning. Customer satisfaction, strongly related to consumers’ quality perception, is achieved only when after-sales service is realized in the shortest time. This is possible when spare parts logistics and repair capacity are adequately set. For example, when carrying out a warranty program for a complex system, maintenance activities have to be planned, thus requiring spare parts. Decisions concerning warehouses and inventory levels must be strategically taken in order to provisioning an effective product warranty service to the lowest cost. Moreover, most activities of the warranty, especially logistic ones, are often outsourced and their efficiency affects not only warranty costs, but also quality perception.

On these considerations, the paper addresses the problem of warranty management efficiency, in particular for complex system such as a custom-built product, where multitude components and conditions must be taken into account. More in details, the adoption of logistic support principles to the definition of strategically important warranty issues is proposed.

The paper is organized as follows. In section 2 a framework for warranty management is proposed, suggesting the use of well-established methodologies, coming from different disciplines, to improve process efficiency. In section 3 the main issues of warranty logistics are presented, whereas in section 4 the proposed methodology for the application of logistic support to warranty management is illustrated. Finally, conclusions and hints for further research are presented.

2 THE WARRANTY MANAGEMENT FRAMEWORK

In previous contributions a framework for warranty management has been presented, in which well-known techniques and methods are suggested to increase process efficiency (Gonzalez Diaz et al. 2009 & 2011 b). The proposed process for warranty management consists of four steps, following the PDCA cycle and principles of Quality Management Systems according to 9001:2008.

The first step of a warranty management process consists in the definition of generic and specific objectives. This decision is fundamental for the strategic formulation of warranty plans and it must take into account different perspective. To avoid contradictions between the warranty program and the overall business strategy the use of the Balanced Scorecard (BSC) in this stage is suggested. Other useful methods to use during the planning phase are Criticality Analysis (CA) and Root Cause Failure Analysis (RCFA) in order to focus actions on those high impact specific failures showing rare and high failure frequency (González Díaz et al. 2011 a).

After establishing the objectives, warranty capacity (spare parts, warranty tasks schedule, skill levels, etc.) needs to be assessed with the aim to attend warranties at the minimum waste or expense. Reliability Analysis (RA) and Maintenance Design Tools (MDT) can be adapted to the warranty field to help the warranty program design. Another important analysis is the Warranty Policy Risk-Cost-Benefit Analysis whose results will depend on the information available.

Once designed, planned and realized, the warranty program must be measured. Performances of warranty tasks have to be evaluated and assessed. Starting from warranty program feedback data, a RAMS (Reliability, Availability, Maintainability & Safety) analysis may help improving product engineering and manufacturing. Another interesting issue is the warranty contribution to the life cycle cost of the product in terms of repairing costs, spare parts, etc.

The last step of the process is warranty program improvement. Considering the large number of possible approach, the adoption of Customer Relationship Management and Six Sigma seem to be particularly effective. Other tools that can be used for the improvement are related to the implementation of new technologies such as e-warranty strategies, where e-warranty can be defined as a warranty program support which includes the resources, services and management necessary to enable proactive decision. This support not only includes e-technologies, but also e-warranty activities such as e-monitoring, e-diagnosis, e-prognosis, ... etc.

3 WARRANTY LOGISTICS

As already outlined, while carrying out the warranty program, logistic issues are crucial for its efficiency and must be taken into account during the whole process, from planning to improvement plans. When a product fails during its warranty period, the manufacturer or his agent is obliged to provide warranty servicing. This implies additional costs for the manufacturer so that an optimization of servicing strategy is needed.

While both warranty and logistics literature is vast, the problem of logistics of warranty servicing has not been deeply analyzed (Murthy et al. 2004). Murthy proposes the following classification of strategic, tactical and operational issues concerning warranty servicing. (Table 1).
In facing these issues, product characteristics are fundamental as for warranty policies. In this field, literature contributions are mainly related to commercial products, dealing with specific problems. For example, Considering the replace or repair issue, there are numerous approaches to support this decision (Murthy & Nguyen, Jack & Vander Duyn Schouten 2000, Jack & Murthy 2001, Zuo et al. 2000).

On these considerations, in this paper some of the above mentioned tactical and operational logistics issues are discussed, focusing the attention on complex products which need to be maintained over their life. For these systems, such as military aircrafts, logistic support becomes a crucial part of the warranty management policy, considering characteristics of products and existent constraints, especially in the military field.

4 LOGISTIC SUPPORT APPLIED TO THE WARRANTY MANAGEMENT

Logistic support deals with provisioning, procurement, materials handling, transportation, distribution and warehousing of items and the support infrastructure needed for carrying out these activities over the life of the product (Murthy et al. 2004). According to this definition, it becomes clear how many aspects of a product logistic support influence the efficiency of a warranty management policy.

Following paragraphs describe how, in order to attend warranties at minimum waste, expense, or unnecessary effort, it is necessary to design an adequate plan for the warranty program. For a complex product this plan will require identifying its functions, the way these functions may fail and then to establish a set of applicable and effective tasks, based on considerations of product safety and service economy. Additionally to this, an initial maintenance plan, applied to the warranty time horizon, can provide a first approach to warranty capacity planning, spare parts provisioning, warranty task schedule, technicians’ skill levels, etc. Planning and scheduling improvement applied to a warranty program can of course enhance the effectiveness and efficiency of program policies. Such improvement will depend on the time horizon of the analysis.

Starting from logistics issues illustrated in section 3, in this section reference models to guide the decision making process are presented, concerning the following critical aspects:

- classification of critical components of the product which, due to their significance according to different factors, deserve to be specially analyzed for the warranty management;
- choice of repair levels, which are those maintenance levels that are more effective to take the proper actions during the development of a warranty program;
- tasks definition which refers to those methods that define the maintenance and warranty tasks when a component, in a specific product, fails;
- required spare parts and allocation.

4.1 Classification of components

In the definition of logistic support strategy particularly important is the identification of candidates, which are elements to be considered for the logistic support process. According to MIL-STD-1388-2B logistic support candidates can be defined as follows:

- Logistic Support Full Candidate: components requiring that their logistic support is analyzed. The knowledge about the logistic support of crucial elements or parts of the product is highly relevant in order to plan, schedule, and organize a proper maintenance and warranty program.
- Logistic Support Administrative Candidate: these are components that do not require a complete analysis of their logistic support, but they are necessary to be taken into consideration to perform the complete analysis of full candidates. In other words, an administrative candidate is the one which has to be manipulated in order to access other candidates of the product.

In Figure 1 a procedure to select the corresponding types of candidates mentioned above is proposed in the form of a flow chart. In this framework, component reliability is considered as the first factor. Those components presenting a high failure rate will be selected to be included in the full candidate list. In order to limit or restrict the amount of components in the list, threshold limits can be set for the failure rate (in operating hours, kilometers, etc. depending on the type of product). The second factor in the flow chart is maintenance; those components requiring intensive preventive

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Table 1. Strategic, tactical and operational issues concerning warranty servicing (Murthy et al. 2004).
maintenance, whose maintenance tasks require specific staff training, or those components presenting a high technical maintenance complexity and documentation will be also full candidates. The third factor depends on the components’ needs of support equipment (for diagnosis) or special tools (for repairs) to carry out the development of maintenance, either preventive or corrective, as well as warranty tasks. In addition to this, a forth factor is the criticality. In this case, candidates will be those components whose failure affects the safety of the product or the user, altering the fulfillment of the product function. There are four standardized levels to measure the criticality (MIL-STD-1629):

- Catastrophic: failure can cause the loss of the entire system.
- Critical: failure can cause serious damages to the system so the product cannot achieve the success of its functions.
- Marginal: failure can cause damages to the system, so there is a delay or loss of product availability.
- Minor: failure is not serious enough to cause damages to the system but an unscheduled repair will probably be required.

Finally, the fifth factor considered is the accessibility of the components. We consider that a component will be an administrative candidate when (although it is not fulfilling the requirements for full candidates) it is necessary to be removed to have access to other product full candidates. To conclude, if a component does not meet any of the above criteria, it will be considered as non-candidate.

As a simplified example to distinguish between the concepts “LS Full Candidate” and “LS Administrative Candidate”, let us consider a complex item as a Thermal Camera which is installed in a vehicle or an aircraft under a Hatch. With the use under standard conditions, the Thermal Camera shows a quite significant low reliability. That means, the Camera presents a very high failure rate so it fulfills affirmatively the Factor 1. Therefore, this item is a LS Full Candidate. On the other hand, the Hatch does not need any special maintenance or support. This is actually a non-critical component in the whole structure of the vehicle or the aircraft. However, such Hatch must be manipulated frequently because the component under it (that is the Thermal Camera) requires support with a high periodicity. Consequently, the Hatch is here a LS Administrative Candidate in order to be also considered during the repair task definition.

4.2 Repair levels

Once logistic support candidates have been selected a Level of Repair Analysis (LORA) can be carried out. Notice that the choice of the repair level presents a high influence on the logistic support in terms of cost-effectiveness. The aim of the analysis is indeed to choose the proper action, not only during the development of a warranty program, but also during the rest of the product life cycle. The repair levels used in this paper have been extracted from the military sector (MIL-STD-1390D) (See Table 1). Considering military aircrafts, other terms commonly used are also LRU (Line Repairable Unit), which are immediately replaced on ground, and SRU (Shop Repairable Unit), which are substituted once the removed LRU is at a maintenance depot.

The proposed framework suggests a way to evaluate and determine how and where a maintenance or warranty task should be executed, in order to afford the lowest cost. Using the already developed notation for the military sector (Table 1), it is possible to define the levels or echelons at which maintenance tasks must be performed according to a cost minimization criteria. Repair cost at each level ($C_1$, $C_2$, $C_3$, $C_4$) can be calculated knowing the...
Then, it is possible to minimize an objective function in order to determine which echelon is the most recommendable to face a repair. A fifth echelon related to reconstructions and major changes performed by the own industrial maintenance (overhaul) is sometimes considered.

Following the simple case about the Thermal Camera, let’s consider now the following example just to illustrate a suggestion to decide the repair level. Particularly, we will analyse if it would be more economical to discard the faulty Camera, rather than repair it. For that intention, we will compare the relative value of a repaired Camera with the cost to buy a replacement (for this generic case, the possibilities in the market will be denominated as A, B and C):

- Condition applied by the manager to take a decision:

If \((\text{MTBF2}/\text{MTBF1}) \cdot N < (L + M)/P\)

then discard

where:

\[
\begin{align*}
\text{MTBF1} &= \text{MTBF of a new Camera} \\
\text{MTBF2} &= \text{MTBF of a repaired Camera} \\
N &= \text{Predetermined acceptance level (set by the company or contractor)} \\
L &= \text{Labor required to repair the Camera} \\
M &= \text{Material required to repair the Camera} \\
P &= \text{Unit price of a new Camera}
\end{align*}
\]

Possibilities:

- Computations Results:
  - A: 0.60 < 1.00
  - B: 0.48 > 0.12
  - C: 0.30 < 0.60

- Decision:
  - A: Discard
  - B: Repair
  - C: Discard

Basically, this simplified example shows that if the cost for the repair exceeds a given percentage of the cost of a new item, the decision should be to discard the failed item. A similar way can be followed to decide between the other repair levels.

4.3 Task definition

In literature many methods are described to define maintenance and warranty tasks when components of specific product fail. Considering the military industry, one possible approach is certainly the use of Reliability Centered Maintenance (RCM) (MIL-STD-1629 6A). In a warranty management context, RCM becomes a dependability analysis for the definition of those tasks to be performed during the warranty period.

Although maintenance and criticality of components are considered in the selection of logistic support candidates (Fig. 1), a deeper analysis is needed to define specific tasks. In particular, failure modes instead of components must be evaluated at this point. The use of RCM strategy to define the warranty program can be easily explained considering a typical RCM process which consists of the following steps:

- Selecting systems and collecting information
- System boundary definition
Once logistic support candidates have been selected, the criticality of their failure modes must be assessed to decide whether preventive or corrective maintenance should be adopted. This choice is of fundamental importance for warranty task definition and system logistic support. For example, when adopting a corrective policy, spare parts provisioning becomes even more crucial.

Within RCM, the criticality of a failure mode can be assessed by using the Safety Hazard Severity Code (SHSC) as catastrophic, critical, marginal and minor failure (already mentioned in section 4.1) or through a more quantitative assessment (MIL-STD-882):

\[ C_m = \lambda_p \cdot \alpha \cdot \beta \cdot t \quad (1) \]
\[ C_r = \sum (C_m)_n \quad \text{with } n = 1, ..., N \quad (2) \]

where:
- \( C_m \) (modal criticality number): it is calculated for each failure mode of each logistic support item.
- \( C_r \) (item criticality number): it is calculated for each logistic support item.
- \( \lambda_p \) (failure rate): it is usually obtained from failure rate predictions (MIL-HDBK-217, RIAC 217 Plus).
- \( \alpha \) (failure mode rate): It is usually obtained from failure modes database sources such as (RAC FMD-97).
- \( \beta \) (conditional probability): It is the analyst's best judgment that the failure will occur, based on the item severity classification.
- \( t \) (mission phase duration): in military or aerospace sectors, it is an average data of the usual system functioning.

Once maintenance tasks to be applied during the warranty period (and beyond) have been determined, it is the moment to define task frequency. In general terms, the evaluation of these intervals depends on experience and product engineering. Nevertheless, it is advisable to calculate this task frequency using (but not exclusively) the following formulation (MIL-STD-1388-2B), where factors to compute the task frequency are characterized:

\[ TF = \left( \frac{1}{MTBF_{tec}} + \frac{1}{MTBM_{in}} + \frac{1}{MTBM_{nd}} \right) AOR \quad (3) \]

where:
- \( TF \) = Task Frequency;
- \( MTBF_{tec} \) (Mean Time Between Failure Technical): Indicator of system reliability that is calculated from known failure rates of various system components and documented by technical characteristics. Technical parameters reflect the technical reliability that the system/equipment must demonstrate. In determining these parameter values, all failures and resultant actions to restore the item will be considered.
- \( MTBM_{in} \) (Mean time between maintenance induced): One of the categories of maintenance events contributing to the mean time between maintenance actions (MTBMA) value. Induced malfunctions are those induced in the system/equipment under analysis from external sources (i.e., other equipment, personnel, etc.).
- \( MTBM_{nd} \) (Mean Time Between Maintenance No Defect): One of the categories of maintenance events contributing to the mean time between maintenance actions (MTBMA). These events consist of removals, replacements, and reinstallations of equipment due to erroneous failure indication. The MTBM NO DEFECT shall be developed by using historical data and field feedback information from similar items to establish the number of maintenance events that are the result of erroneous failure indication. An alternative procedure approved by the requiring authority may be used in lieu of the above procedure.

AOR = Annual Operating Requirements.

4.4 Required spare parts and allocation

Once obtained the frequency for a specific task, it is possible to determine the required spare parts. For that purpose, it is necessary to know previously the following parameters:
- \( \text{Task Frequency per Year and Product Unit (TF)} \)
- \( \text{Spares Quantity per Task (QT)} \)

With these data it is possible to obtain the Spare Parts Frequency per Year and Product Unit:

\[ \Lambda = \sum (TF \cdot QT) \quad (4) \]

Considering a very complex system, like the military air force or navy, this data allows the definition of spare parts allocation in warehouses of different echelons. In fact, logistic support for military systems is usually carried out in strong collaboration with the manufacturer during the warranty period and longer. In some cases the whole logistic support process is outsourced to the manufacturer. In this context warranty program efficiency is sensibly affected by logistic decisions such as spare quantity and allocation. There exist numerous approaches to this problem (Kennedy 2002)
depending on number of echelons, distribution for spare part demand and possibility of lateral transshipment between different echelons. An example of spare parts allocation and inventory management for military aircraft components is reported in (Costantino et al. 2010).

5 CONCLUSIONS

Throughout the paper various aspects of efficiency related to the improvement of the warranty management have been discussed. After presenting most important issues of warranty management and proposing a framework for its management, it has been analyzed the logistic support applied to complex products and how this support can be focused to facilitate and improve the decision-making process. Additionally, it has been shown how concepts should be repaired, determining concepts as task frequency and distinguishing different levels of repair. Improvements in warranty management efficiency, as well as the consequent increase in customer satisfaction, may represent a key aspect in a global competition.

About the logistic support applied to the warranty management, further research in this field should be focused on the calculation of different costs, combining warranty assistance and maintenance tasks once the warranty period has been expired (in order to possibly extend the warranty contract). Another interesting development could be the combination of RCM with CRM (Customer Relationship Management), considering this as a stage included in the reference framework proposed for the warranty management. Moreover, the integration of RCM solutions with an ERP system (Enterprise Resource Planning) can improve not only the definition of new maintenance and warranty strategies, but also the development of continuous improvement.

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