Approach to Analyzing Root Causes in the Management of Warranty Support

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***Abstract*-This article focuses on one of the steps proposed by the authors as a framework for improving the management of post-sale service. Specifically, the referred step tries to apply root cause analysis of failures to improve the organization of warranty support. This analysis can help make better decisions within the scope of after-sales service, for example, whether a particular incident should be treated under warranty or not.**

This article begins with an introduction to the current concept of warranty, briefly describing the proposed framework and the relevant literature related to such customer service. Thus, the reader can place the step to be developed in a context of useful tools and methodologies for the management of post-sale service. Therefore, the main aspects of Root Cause Analysis are defined with the intention to apply these concepts in the management of those incidents reported by the user.

With this objective, this article aims to adapt a developed and applied tool of the maintenance management (Root Cause Analysis) to a new field, in this case, the customer service. At the end of this article the main contributions for this work are summarized.

Keywords*- *Root Cause Analysis; Technical Support; Warranty Management; Post-Sale Service

I. INTRODUCTION

The warranty is usually defined as those policies for quality warranty that applies to all clients so the goods or services purchased meet their specifications and requirements, otherwise, be replaced or repaired. This service applies for a period of time after the sale of the product. The management of this policy combines technical, administrative and organizational actions during a valid period in order to maintain or restore the item to a state that can perform the desired function [1]. There are different types of warranty appropriate to the type of product (consumer products, commercials, industrials, standard versus custom ...) as mentioned in [2], [3].

A key aspect of warranty management is that the strategic decisions regarding this process should start at a very early stage of product life cycle and not as an afterthought just before the launch phase [3]. Other common problems during the implementation of warranty services are, for example, the following:

- Information systems are often limited;
- Long cycle time for review of claims;
- Excessive number of invalid claims;
- Lack of clarity on the responsibility of the warranty;
- Warranty information is not used to improve product quality;
- Claims are not used to take corrective action in the manufacturing, engineering or product design;
- Other ...

All these problems are negative circumstances that a good post-sale manager should avoid. Likewise, for the effective reliability management of a product it is necessary to take into account the relationship between warranty and reliability [4] (Figure 1).

Fig. 1 Relationship between Warranty and Reliability (adapted from [4])

Authors of interesting contributions [2], generally try to identify: process, actions, scenarios, tools and techniques or methods of support that are necessary to manage warranty costs appropriately. Basically, a system of warranty management which is well established will successfully help achieve the business objective of a satisfactory post-sale service performance. Therefore, with re-engineering of the management processes and the application of a correct model of warranty costs, it is possible to:

- Increase the sale of extended warranties and other related products;
- Improve quality by increasing the flow of information on product defects and their causes;
- Improve customer relations;

- Reduce costs associated with warranty claims and their processing;
- Improve management and control of warranty costs;
- Reduce costs associated with invalid warranties.

In general, the objective of a company is to increase their benefits. From the warranty perspective, to achieve increment of the benefits it is necessary to maximize the reliability and life extension of the products [5]. The objective of the Assets Management (those offered for sale) is to predict both alterations and unexpected operational stops and minimizing loss of performance. Thus, the priority is to determine an efficient sequence of actions, which ensure minimal loss of performance and maximize the usefulness of the product by the user [6].

II. LITERATURE AND BRIEF DESCRIPTION OF THE FRAMEWORK

The warranty and maintenance requirements have changed dramatically in recent times as well as evaluation of strategies and task selection. Recently the overall management of maintenance and post-sales in an organization cannot be done randomly and informally [7]. The objectives of any real context of maintenance management and warranty are determined and dependent on the business plan of the organization in question. Therefore, strategies must always be aligned with the business plans of the company [8] as this depends on the after-sales objectives and also those of the organization's business plan. Through different case studies [9], [10] and especially in the review of the Literature [1] [11], different interactions can be observed between warranty, maintenance, and other disciplines, which are used differently by a range of authors (Table 1). To summarize, four important interactions can be considered:

A. *Warranty and Maintenance*

In many cases, the warranty period is the time in which the manufacturer still has some control and knowledge about its product and behaviour. The expected costs of warranty typically depend not only on their own warranty requirements, but also the maintenance program associated with the product [20].

B. *Warranty and Outsourcing*

The warranty support service or, in general, post-sales department in a company, is usually one of the most likely to be outsourced due to its low risk and also to the legal protection that provides contracting technical support services [25, 26].

C. *Warranty and Quality*

Improving the reliability and quality of a product not only has a positive impact and advantage for the client, but also greatly reduces the expected cost of warranty [27].

D. *Analysis of warranty and other costs*

In reference to the cost estimates, there are now methods to calculate, with some precision, the final cost of a specific procurement contract, for example, a method called EAC or "Estimate at Conclusion" [28], which is a technique used in project management to control and track costs.

TABLE I SOME IMPORTANT CONTRIBUTIONS IN WARRANTY

Case	Year	Subject	Ref.
1	1976	Modeling general warranty costsfor a future period.	[12]
2	1989	Warranty costs with a use-dependent model.	[13]
3	1993	Estimated warranty costs with an integrated multi-criteria model.	[14]
4	1999	Warranty, considering replacement time and cost risks.	[15]
5	2001	Effects on warranty with an imperfect model on themanufacture quality.	[16]
6	2001	Warrantypolicy with time-dependent costs.	[17]
7	2003	Cost estimation considering renewable warranty policies.	[18]
8	2004	Non-renewablewarrantiesconsidering repair times.	[19]
9	2004	Fault/repair model on warranty depending on age.	[20]
10	2005	Time between overhauls of quasi-renewal in the warranty costs.	[21]
11	2006	The warranty considering imperfect repairs and preventive maintenance.	[22]
12	2006	Non-repairableservices and products related to warranty costs.	[23]
13	2007	Warranty cost model related to the software reliability.	[24]

Due to these reasons and according to the experience observed in several case studies, as described in References [9] and [29], a reference framework is proposed for the warranty services management, using engineering techniques already developed and applied and other similar processes (Figure 2).

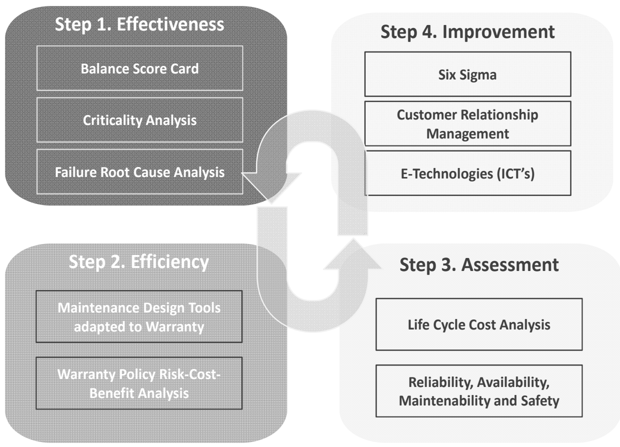

Fig. 2 Proposed Framework for warranty management

This generic and developed framework is detailed in Reference [30], which integrates management methods, already defined that are collected in four sequential phases where different techniques play a crucial role. Following this scheme, the framework is defined as a support for the management of a warranty program (as a sequence of activities), thus providing a practical overview of all the stocks that make up each area of management, and focusing not only on improving the reliability of the product, but also in the relationship between manufacturer and user. Through the re-engineering of the management processes and through the application of sound warranty management, it is possible (among other characteristics) to influence the design and the manufacturing of the product. Therefore improving quality and reliability by increasing the flow of information related to their shortcomings and causes. This article is particularly focused on root cause analysis, which is integrated in Step 1 (Effectiveness).

III. THE ROOT-CAUSE ANALYSIS FOR IDENTIFICATION OF PHYSICAL CAUSES IN THE EFFECTS ON WARRANTY

The development of new technologies and practices in management implies that the technical team of customer support should be provided with technical and management skills [31], thus justifying the use of more complex tools that can generate more accurate maintenance and warranty solutions to minimize the uncertainty. Several methods have been proposed in the literature for planning post-sales activities of complex products launched to the market. The implementation of maintenance methodologies significantly reduce warranty costs by focusing on the root causes of failures, for which two tools, Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM), adapted to customer service, are useful to address and overcome these challenges [32].

More specifically, the RCM is a tool that integrates the practices of Corrective, Preventive and Predictive (or condition-based, CBM) Maintenance strategies. This tool is designed to minimize maintenance costs [33] by balancing the high costs of corrective maintenance with the costs of scheduled maintenance (preventive or predictive) policies, taking into consideration the potential loss of lifetime of the equipment in question [34]. The RCM itself, as well as its adaptation to the case of warranty management (Figure 3), analyzes the functions and failures of a system and identifies the consequences of these, to implement preventive measures using a logic and standardized resolution procedure [35]. However, the analysis does not involve a thorough investigation to identify failure mechanisms and the real causes of it [36].

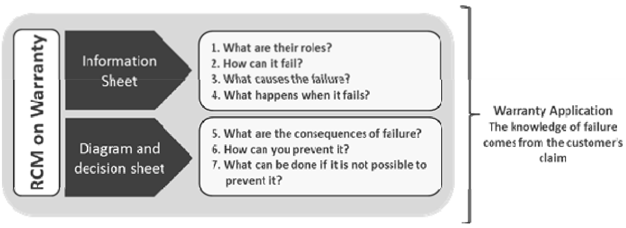

Fig. 3 Implementation of a RCM method to the warranty casuistry

Proactive Maintenance uses tools such as Root Cause Failure Analysis (RCFA), Failure Mode and Effects Analysis (FMEA), Criticality Analysis (CA), Acceptance Testing (AT) and Age Exploration (AE). Some authors make a distinction and identify a sub-branch in the Proactive Maintenance, called Radical Maintenance (RM), which involves the detection and prediction of root cause failures, and later takes appropriate measures to eliminate the root causes or conditions that induce them [37]. There are a wide variety of tools and methods to determine the root causes of certain events or failures [38]. These vary in complexity, quality of the information required and applicability of their results. In general, the most commonly used are shown in Table 2.

TABLE II METHODS TO DETERMINE ROOT CAUSES

	Methods to determine the root causes
Quantitatives	• Fault Tree Analysis (FTA) • Pareto Analysis • Bayesian Inference
Qualitatives	• Analysis of the 5 Whys • Ishikawa diagram. • HAZOP

These methodologies that have substantial differences can be categorized into qualitative and quantitative [39, 40, 6]. While qualitative methods are usually performed in the form of brainstorming; quantitative methodologies can even need complex mathematical methods. Other tools include:

- Change Analysis
- Current Reality Tree (CRT)
- Failure Mode and Effects Analysis (FMEA)

The importance of using Root Cause Analysis tools for the maintenance is the need to understand the main causes of failure, on which the administration, management or operation may have an impact, in order to avoid chronic and recurring failures with a specified plan of action. In this sense, it is not solely enough to find the root causes of failures, but it is necessary to generate essential preventive and corrective actions, which is why the use of these tools plays a vital role. Bayesian Networks (BN) can be used as a support for decision making based on a probabilistic reasoning as they allow for calculating probabilities of future events and are able to adapt to changes [41]. Moreover, the purpose of monitoring and diagnosis is to integrate prior knowledge of the processes with the physical current evidence observed. Therefore it generates the most plausible explanation of the process behaviour. The Bayes' theorem incorporates this type of predictive support in the diagnosis [42]. The flow chart below (Figure 4), based on the work of [7], [36], shows the location of the different methodologies of Root Cause Analysis in a model of maintenance management by stages. From the flow chart below, the following can be observed:

- The Pareto Analysis is at the stage of ranking of critical equipment, because along with the criticality matrix it can help determine which equipment is critical to a systemic level.

- The FMEA can be used in the stage Weak Point Analysis of critical equipment, where an assessment of causes, failure modes and effects can be considered relevant.

- The Critical Analysis helps determine whether the weak points of critical equipment are significant in the performance of the system.

- The FTA or Bayesian inference can be used for more complex analysis for determining the root causes of equipment failures and weak points critical to both the system and for correct development of the plan of action defined on the basis of maintenance strategy implemented.

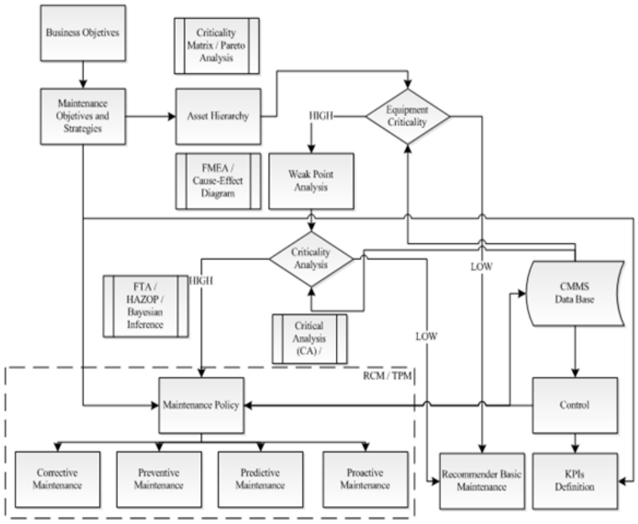

Fig. 4 Location of the RCA methodologies

For all the above, it is noted that optimal performance of the methodologies is achieved when they are properly used for a specific requirement of a particular stage within the framework of the overall post-sale service management. This, however, depends on their characteristics and the requirement of information and resources.

IV. MODELS OF ROOT-CAUSE ANALYSIS AND ITS APPLICATION TO POST-SALE SERVICE

A. Classification According to the Approach

The root cause of a failure can be defined as the most basic cause which can be reasonably identified and that the organization has control of it [43]. The literature that supports this approach determines that there are three levels of root cause of the failure in a system:

- Physical Root Cause: Failure of equipment caused by physical reasons.
- Human Root Cause: Failure of equipment caused by human intervention.
- Latent Root Cause: Failure of equipment led by decisions at organizational level that triggers an event of failure.

The Failure Analysis (FA) or Root Cause Analysis (RCA) consists of examining in detail the items that reach the state of failure to determine the root cause of it and improve system reliability [44]. This process identifies causal factors using a structured approach with techniques designed to achieve the proper orientation and to allow the identification and problem solving. Its execution eliminates or minimizes those root causes that can generate recurring failures, not focusing on the actual consequences of failure [45]. Among the methods of root cause analysis four groups can be distinguished as shown in Table 3 [46].

TABLE III CLASSIFICATION OF THE RCA GROUPS BASED ON ITS APPROACH

Root Cause Analysis Groups	Description
Deductive	Approach that involves reasoning from general to specific (Example: Fault Tree Analysis).
Inductive	Approach that involves reasoning from individual cases to general conclusions, providing a general approach (Examples: Cause and Effect Diagram, HAZOP analysis).
Morphologic	Method based on the structure of the system under study. It focuses on the potentially dangerous items, concentrating on factors that have the greatest influence on system's protection.
Techniques not oriented to systems	Concepts and techniques not oriented to systems like the above (Examples: Change Analysis, Study of Human Error Probability).

B. Most Commonly Used Methodologies of Root-Cause analysis

The most commonly used methodologies of RCA analysis in Reliability Engineering will be briefly explained, highlighting its benefits and limitations. These are:

- Failure Mode and Effects Analysis (FMEA): An analysis of failure modes, effects (FMEA) and criticality (FMECA) is a qualitative method that identifies potential failure modes and analyzes the consequences on the system of all possible failures that may affect a component, which also proposes measures to avoid or minimize the consequences thereof in the system [47]. The method systematically analyzes the failure modes at a component, equipment and subsystem level and assesses the effects and criticality (FMECA) in the system and the probability of occurrence [36]. It basically identifies areas that need improvement to ensure that the system be more reliable and secure (globally) in the performance of their duties. The method is an inductive approach, starting from the component failure and following the effect it produces through the system, looking for all possible consequences. Within its limitations, it highlights a low performance in complex systems' problems, due to an inability to show causal relationships based on evidence beyond the specific mode of failure that is being analyzed [39]. Furthermore, its effectiveness is limited by the experience of the working group that is operating it.
- Fault Tree Analysis (FTA): A quantitative deductive method that begins with the search for an undesired event, which is called "High Incident", in order to analyze the causes of this event and to quantify the probability of occurrence. The root cause analysis is performed using a logic diagram which reflects how the combination of several elemental events leads to the occurrence of a High Incident. The FTA is a graphical representation of events in a hierarchical order, which allows identification and classification of possible events (represented graphically as a tree-like pattern) that can cause a system failure, and estimate the system failure probability. It is widely reported for its ease of use, and because it features an intuitive and high level of abstraction of the system. The diagram is drawn by conventional logic symbols, so the causal relationships can be identified with "Y" and "O" or various combinations of the same.

With this detailed information, efforts to improve safety and reliability of a complex product that is sold, are more focused and adapted to the system in question. In addition, fault tree analysis can help prevent the occurrence of failures as it provides data that show how and under what circumstances may occur, determining the importance of each critical element of the system. This technique is applicable to static and dynamic complex systems. It provides an objective basis to analyze the design of a system and its common causes of failure. It also allows the compliance of the safety requirements to be checked and to justify changes and additions. Its limitations exist because it is unable to function correctly as a root cause analysis. This is because it cannot handle functional or sequential dependencies between components, and that it requires the use of specific information related to known reasons of component failures. However it is often used to support the RCA and needs the use of specific information related to known reasons of component failures [39].

- Cause and Effect Diagram (CED): is a tool that breaks down the potential causes into more detailed categories, so they can be organized around and related to factors that help identify the root causes [45]. Also known as Ishikawa diagram or fishbone diagram. Its limitations are due to not showing all the causal relationships between the primary effect and the root cause, as well as not providing evidence to support causes factors [39].

- Pareto analysis: a statistical approach to problem solving that uses a database to identify the number of predefined causal factors that have occurred in the system. It is based on the Pareto principle, which assumes that the 80% of the problems are caused by 20% of causes. The Pareto analysis, which is sometimes misused as an RCA method, receives better use to define the beginning of an analysis. They are also commonly used to determine maintenance priorities ordering equipment failure codes according to their relative cost or contribution to downtime. It is limited by the accuracy of the information that is conducting the test, and loses the causal connection of the principle of cause and effect [39].

- HAZOP: This methodology, whose name comes from Hazard and Operability, has become the cornerstone of risk studies of process plants. The HAZOP study allows qualitatively determining the consequences of a system when varying the conditions of operation or design [40]. This study is traditionally performed as a structured brainstorming exercise, facilitated and led by a leader of the HAZOP study that uses the collective experience of participants. To achieve the objective of the study, the following essential questions need to be addressed: “What deviation can happen?”, “What process parameters are relevant to measure?” “Why deviations occur?” (Causes), “How are they expressed?” (Consequences). In a HAZOP study these questions are completed after dividing the total system into its constituent parts, such as sections and nodes. The questions posed relate to the objective of the system while the process is the means to achieve these objectives. The HAZOP study limitation is the requirement of time and resources at any time in which it is performed during the life cycle of the plant. A further step in the study would be to search, quantitatively, the range of deviations limits from the nominal values of design, in which the equipment continues to maintain its capability and the system stays operative.

- Bayesian Inference: Bayesian networks are one of the most widely applied techniques in probabilistic inference, as they provide a flexible framework to evaluate and model uncertainty. Thus, Bayesian networks (in graphical form) are made up of nodes representing random variables connected by arcs that quantify a causal relationship between the nodes, and in which each of these represents a random variable that can take two or more discrete values.

The monitoring of process and failure diagnosis requires the assumption of a certain number of information sources, which may not be entirely accurate or incomplete, in order to infer when a change has occurred in the state of a process or equipment and to identify the root cause of that change. Such inferences are necessarily imperfect, and are of value if the conclusions can be argued with some quantifiable measures despite the uncertainty [42]. Two types of inferences can be supported and considered using Bayesian networks: the diagnosis and predictive approach [48].

During the operation of a process, if there are abnormal changes in the conditions, and they are not identified and corrected, events known as failures can be generated. A causal representation of the facts through Bayesian networks generates a chain of events and transitions, which are interesting for the root cause analysis under uncertainty and for the purpose of supporting decision making on appropriate corrective actions [6]. Figure 5 shows a Bayesian network model for RCA, in which a set of root causes (Hi) contains all possible sources of failure hypothesis, which can eventually lead to different events or failure modes (Sj) representing symptoms that precede a failure (F). The symptoms involve changes in operating conditions, which affect computer performance and outcome of the operation.

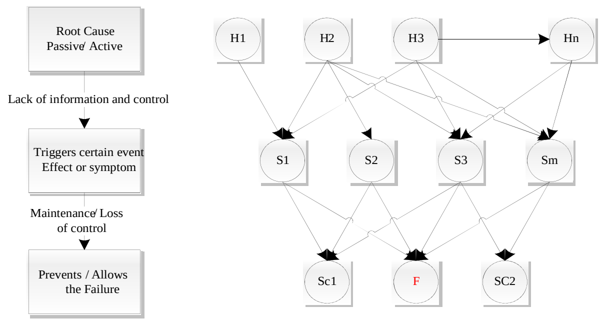

Fig. 5 Concepts and variables in a BN Root Cause Analysis. (Based on [6])

Bayesian networks have proven to be useful for a wide variety of predictive and monitoring purposes. Related applications have been documented in areas such as the medical and image processing, among others [42]. In Manufacturing, BN has also been used as a method of monitoring and real-time diagnostics to identify component failures in multi-stage process [49]. Given the need to make decisions regarding Maintenance Management, Bayesian networks are a very suitable methodology in combination with methods to support decision making (Decision Support). The Decision Support (DS) is a computer information system that supports decision making of organization or business in companies. A correctly designed DS is interactive software that compiles useful information from a combination of raw data, documents, people's knowledge or business models which identifies, and helps to solve problems and make decisions. The Analysis of Alteration (that includes the RCA and the DS) in an industrial control process, it has, as a global purpose, to remove the necessary information for the early evaluation of abnormalities from the maintenance databases. Also, it identifies and solves problems in the operating and maintenance procedures [6].

C. Proposal for the Warranty Program

Previous sections have shown that there are different methods previously developed to perform an analysis of weak points in a released product. As it has been seen, the root-cause analysis considers actions in order to discover the reason for the appearance of a specific failure and how to correct the causes. A possible classification of the causes may be, of course, to know whether the incidence must be addressed by the warranty or not (Figure 6), with emphasis on those claims with reasons still unknown.

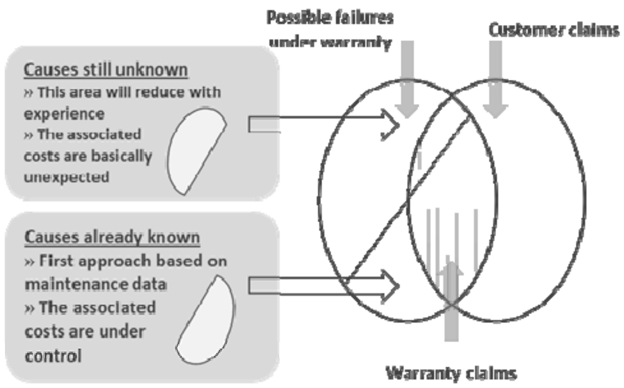

Fig. 6 Possible classification of causes

In any case, this analysis will help restructure the considerations initially adopted in the earlier stage of the proposed framework (the Balance Scorecard), thus improving the effectiveness of the warranty program. A detailed root cause analysis of failure may consist of:

- Determining the root cause of the fault;
- Proposing, testing and validating hypotheses;
- Recommending preventive actions;
- Implementing improvements;
- Forming a team of experts;
- Gathering evidence;
- Analyzing results and determining the causes of failure.

To assist warranty with minimal waste, expense or unnecessary effort, it is essential to design an appropriate plan for the warranty management program. The plan for a particular product, first, requires the identification of their functions and how these functions may fail, then establish a set of applicable and effective tasks, based on considerations of safety of products and services. One method that can help develop this plan at the beginning of the warranty program can be extracted from the management techniques of field maintenance. In particular, it will be useful to apply an adapted reliability analysis and design tools for maintenance, for example, the use of FMECA described previously for the generic design of a maintenance plan. An initial maintenance plan, applied during the warranty period, can make a good first approximation for the planning of capacities under warranty, spare parts procurement, scheduling support tasks, level of training for the technicians, and so on. The planning and programming improvements applied to post-sales management can of course improve the effectiveness and efficiency of policies of the warranty program. This improvement will depend on the period of analysis.

V. ADVANTAGES AND DISADVANTAGES

Tools or methodologies previously described have advantages and disadvantages inherent to each. Depending on the type and depth of analysis performed, it is necessary to evaluate each methodology to use only the one that best suits the needs addressed. While all methods have the ability to define the problem analyzed, the cause and effect diagrams do not show any causal relationships between the primary effect and the root causes. Moreover they are unable to deliver a clear path to the root causes as they only categorize isolated causes into groups that produce a primary effect. However, they have a low level of requests for information and resources and are relatively easy to use [39].

Table 4 presents a comparative summary based on a set of criteria for the methods commonly used in RCA analysis. An initial maintenance plan, applied to the period under warranty, can make a good first approximation for: the planning capacities under warranty, spare parts procurement, scheduling support tasks, the level of training for the technicians, etc. The HAZOP method is a structured study in the form of brainstorming and is developed by individuals who are involved in the problem solving process. Therefore, it is highly dependent on the experience of those individuals and should be conducted in several sessions, which requires time and other resources. Their advantage lies in the plans developed to prevent recurrence [40]. The FMEA is effective in finding the causes of component failure; however, it loses its ability to solve complex problems because they cannot establish causal relationships beyond the failure mode being analyzed. The Fault Tree Analysis is a quantitative method that works extremely well in engineering problems, finding causes related to the original system design, identifying scenarios, and selecting appropriate solutions, where human factors are not included [39].

TABLE IV COMPARISON OF SOME RCA METHODOLOGIES [36], [39], [40], [42], [45], [47], [48]

RCA Methodology / Features		Ability to define the problem	Ease of Use	Information Requirements	Depending on the experience of the users	Resources and time consumption	Definition of all causal relationships	Delivery of a path to the root causes	Explain how solutions prevent recurrence	Ability to include human error	Prediction of future events
Cause and Effect Diagrams	High	✓	✓		✓					✓	
	Low			✓		✓	✓	✓	✓		✓
HAZOP	High	✓		✓	✓	✓	✓		✓		
	Low		✓					✓		✓	✓
Bayesian inference	High	✓		✓		✓	✓	✓	✓		✓
	Low		✓		✓					✓	
FMEA	High	✓	✓		✓	✓		✓			
	Low			✓			✓		✓	✓	✓
Fault Tree Analysis	High	✓	✓	✓			✓	✓	✓		
	Low				✓	✓				✓	✓

For its part, the Bayesian Inference, even when it requires more resources and has an inferior ease of use, it has great capacity to establish causal relationships for a large number of variables and is suitable as a support for decision making to prevent recurrence [6]. Its structure facilitates the combination of prior knowledge, either causally or obtained from observed data. Bayesian networks can be used to: learn causal relationships, facilitate the understanding and how best to analyze the problem, and to predict future events [50, 48].

VI. CONCLUSIONS

This article has described a specific tool already developed in the area of maintenance, with the intention to apply in the management and organization of warranty support. With this intention, once the warranty concept has been defined and the framework proposed for its management has been briefly described, the different methodologies, that include the possibility of a Root Cause Analysis, are analyzed. These methodologies facilitate and improve decision making in cases such as post-sales service. It is observed that the difficulty to reach robust results, when using one of the methodologies, is the use of only one approach, given that a qualitative analysis of a brainstorming type can leave aside a significant amount of information on quantitative data; while a purely numerical approach might be biased because it does not take into account considerations such as, experience or relevant qualitative information.Using a single method may lead to an incomplete analysis; therefore, in specific cases an integration of Root Cause Analysis tools can be appropriate to obtain better results, especially when dealing with complex systems [51]. In fact one of the common combinations to support RCA analysis is the FMECA and FTA [36]. In short, there is evidence that the integration of different types of Root Cause Analysis generates more robust results, i.e., each tool unitarily has its own limitations but the integration between them can eliminate the global and individual limitations of each one of them.

This research raises the possibility of identifying physical causes of failure, as well as the malfunction representation of a complex product offered for sale. This is based on the integration of Bayesian Networks, Fault Trees, FMEA and HAZOP study depending on the state of certain variables that, given its dependencies, may trigger a state or event of failure. The integration of these methodologies, as mentioned above, assumes a more robust result in the identification of the main causes of a deviation in performance from the generation of a chain of causality. Future researches in this area can be focused in the application in post-sales service management. For example, once the causes of failures are known, it is possible to assess the costs of the damage [52] using advanced mathematical methods. These methods applied electronic support technologies such as remote surveillance, monitoring, e-diagnostics, etc. in order to develop more elaborate models. In addition, new electronic technologies applied to the warranty, will enable a greater understanding of the root cause of failures and, consequently, higher levels of product quality [53] and increasing the effectiveness of technical support service.

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