Chapter 2
An Initial Case Study. Understanding Warranty Management Issues

Case studies have normally been used to support and help theoretical subjects in engineering and other research fields. When these cases are developed, it is usually found that such an amount of information can either trivialize the study or complicate it beyond a reasonable level. Therefore, the intention here is to synthesize a practical case, which transmits easily how a proper management of warranty assistance helps to reduce costs, enables us to make suitable decisions, and improves the image of the company in front of the client. As mentioned at the beginning of this research, there are different types of warranties according to the different products in the market (consumption products, commercial products, industrial, standard or personalized products, etc.) [1]:

- Standard Products: Free Replacement Warranty (FRW), Pro Rata Warranty (PRW), or a combination of both.
- Commercial Products (purchased in volume): Warranty applied to a fleet or group of items.
- Personalized Products: Reliability Improvement Warranty (RIW).
- Base Warranty and Extended Warranty.
- Etc.

The case examined here deals with a customized product and the warranty management with the client. This study starts summarizing the background related to warranty, highlighting the importance of a warranty cost management system. Once the problem is defined and along with the development of a particular case study, analysis of data and conclusions will be shown. Besides, a procedure is also proposed related to the way of working among different sections inside a generic company. This procedure will be examined succinctly using a workflow chart. Other practical cases in the field of warranty can be found in [2].

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2.1 Background

In order to apply an effective warranty management, it is critical to gather proper data and exchange the different types of information between the modules into which a management system can be divided [3]. In our case, a warranty management will be proposed, as a system based on a several modules organization. In the literature review (this chapter), one can observe different interactions between warranty and other disciplines, and how they are dealt with by the different models and authors. In particular summarizing, three important interactions must be considered:

1. *Warranty and Maintenance*: In many cases, the warranty period is the time when the manufacturer still has a strong control over its product and its behavior. Additionally, the expected warranty costs normally depend, not only on warranty requirements, but also on the associated maintenance schedule of the product [4].
2. *Warranty and Outsourcing*: The 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 also to the fact that, among other features, outsourcing provides legal insurance for such assistance services [5].
3. *Warranty and Quality*: The improvement of the reliability and quality of the product not only has an advantageous and favorable impact in front of the client, but also this improvement highly reduces the expected warranty cost [6]. However, in the vehicle industry for example (see Fig. 2.1), it is probably a simplification to consider a low ratio of client's claims supposes high quality, that is because such situation has to do with those companies that reject customer claims redirecting them to the suppliers. In Fig. 2.1, the axis of ordinate indicates the percentage dedicated to warranties in respect of the income in vehicle sales.
4. *Warranty and Cost Analysis*: In reference to costs estimations (see Fig. 2.2), and apart from warranty issues, there are nowadays several methods to accurately estimate the final cost of a specific acquisition contract. In our case study, the method applied in a simplified way is denominated "Estimate at Completion" (EAC).

In few words, EAC is a management technique used in a project for the cost control progress. Here, the manager foresees the total cost of the project at completion, combining measurements related to the scope of supply, the delivery schedule, and the costs, using for that purpose a single integrated system. Warranty costs can be included in the global analysis of the project, providing the estimation costs of the same service generated at the end of contractual responsibility.

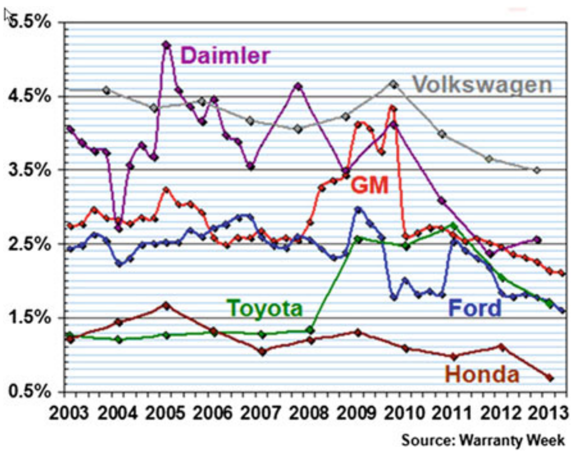

Fig. 2.1 Ratios of warranty claims from 2003 to 2013

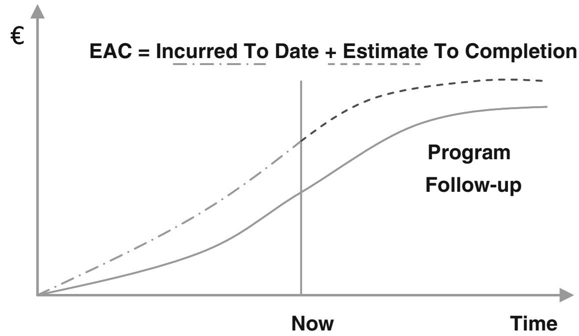

Fig. 2.2 EAC formula (adapted from [7])

2.2 Case Study Scenario

The company that is focused on in the case study is a large manufacturer in the metal industry that operates globally. The company designs, manufactures, and purchases a wide range of industrial vehicles (such as machinery used in forestry, hydraulic excavators, or track loaders) for industrial customers, as well as other related products such as spare parts. In addition to the purchase of standard vehicles, nowadays the customization of machines is also common. In our case, the company must supply the client with a specified amount of customized vehicles on a defined schedule. In the contract, warranty assistance is included for the vehicles of the fleet during a period of time that starts when each vehicle is delivered to the customer. To provide the after-sales service in a satisfactory way, the fulfillment of some conditions is required:

1. Teams formed by properly trained personnel.
2. Tools for maintenance/warranty tasks.
3. Materials and spare parts to carry out the repairs.

The first two conditions are considered fulfilled. Regarding the third condition, the necessary materials for warranty operations are obtained from the same warehouse as the assembly line. This way, there are two possibilities to recuperate the material:

- When the piece is repairable, a spare part is taken from the warehouse, which is later returned after the disassembly of the product being repaired.
- When the piece is not repairable, a spare part is also taken from the warehouse, but it must be restored by the purchase of another.

This situation is possible because the manufacturing stock allows the supply of material for warranty assistance without risking the necessities of the assembly line. The problem in this scenario is defined as follows: Due to the fact that manufacturing and warranty assistance share the same warehouse, there will be instances where the manufacturing is at a very advanced stage and simultaneously there will be many vehicles under warranty. From this moment onwards, every decision made prioritizes one of the two activities. Apart from the context described above, the study takes place during the lifetime distribution of deliverables. This means that, historical data regarding costs, faulty items, etc., are available for the research. In reference to the faulty items, it has been used a classification tree with several levels following a hierarchical structure based mainly on their functionality, and reaching a sufficient level of detail in terms of procurement aspects. In figures, the described scenario and the delivery schedule are shown in Table 2.1. Our case study will be developed considering also the following hypothesis:

- Every vehicle has the same reliability (they have the same failure probability).
- The warranty cost is constant with the time.
- The warranty time does not stop at any moment.

The EAC for warranty depends on company policy. Usually, the budget for warranty is determined as a percentage of the total project cost. In our case study, the total cost, manufacturing plus indirect costs for each vehicle, is supposed, amounts to ca. 375,000.00 € and the percentage for warranty attendance will be 2 % of the budget for total costs. That yields around 2,625,000.00 € for the attendance of warranties during the whole project.

2.3 Analysis, Development, and Results of the Case Study

In the literature review of the previous chapter, many case studies can be found which are related to the data analysis taken from warranty assistance (qualitative and quantitative date). This analysis is based on real data and offers a substantial amount of detail. Two references that offer a complete revision of this topic are [8] and [9].

Table 2.1 Data of the described scenario

Date	Accumulated amount of vehicles
March 2008	Rollout
April 2009	45 units
April 2010	100 units
April 2011	150 units
April 2012	200 units
April 2013	260 units
April 2014	315 units
April 2015	350 units

Total amount of customized vehicles to be delivered: 350 units
Warranty period for each vehicle: 2 years
Warranty expiration for last vehicle: March 2017
Time point of the case study (t_1): April 2011 (150 unit already delivered)

2.3.1 Costs Analysis of the Warranty Assistance

As mentioned, the study takes place when the company has already delivered a number of 150 vehicles. In this time, there are 105 vehicles under warranty. Some preliminary data are shown in Table 2.2. Together with this, there is also a sample regarding the number of vehicles under warranty according to the defined delivery schedule. Some figures here have been rounded off in order to simplify their use during the study.

Table 2.2 (as commented) is only a sample extracted from the complete delivery schedule. From this complete schedule, it is possible to note that the warranty expiration date of the first vehicles is obviously on March 2010 and, also, that the most critical moment (t_2) will be in September 2013. The graphic in Fig. 2.3 can help to illustrate it.

In April 2014 (t_2), the already delivered fleet—315 units—will have a maximum number of vehicles simultaneously under warranty—115 units—(see continuous graphic line). In this moment, we can observe how close the due date of the deliveries is (April 2015). Consequently, much closer (and critical) is the manufacturing of the last vehicles. In t_2, our teams of maintenance/warranty technicians will have to attend a high number of vehicles which will demand a huge number of spare parts. At the same time, the operators of the assembly line will request pieces for the production of the last vehicles. The shared warehouse will have in storage enough pieces for manufacturing, but not for more, so the supply of any spare parts demanded by the after-sales personnel must be carried out taking into consideration the importance of the material, the time to repair the disassembled piece, and/or the time to restore it by purchase. Every piece in the classification tree (see Fig. 2.4) belonging to the lowest level (level where materials can be procured) will have a weight (or critical) which changes with time. Every piece will be considered much more critical as the end of the manufacturing process gets closer. Therefore, and taking also into account a costs analysis, it is

Table 2.2 Extract of the delivery schedule

Date	Accumulated amount of vehicles	Monthly delivery (units)	Vehicles in warranty (units)
March 2008	Rollout	5	5
April 2009	45 unit	3	45
April 2010	100 unit	4	91
April 2011	150 unit	4	105
April 2012	200 unit	4	100
April 2013	260 unit	5	110
April 2014	315 unit	4	115
April 2015	350 unit	2	90
April 2016	350 unit	0	35

Number of delivered vehicles t_1: $V_1 = 150$ units
Number of warranty claims in t_1: $R_1 = 1{,}200$ warranty claims
Warranty incurred cost in t_1: $C_1 = 1{,}000{,}000.00$ €
EAC for Warranty: $\mathrm{EAC}_w = 2{,}625{,}000.00$ €
Number of vehicles to be delivered: $V(t) =$ (according to delivery schedule)

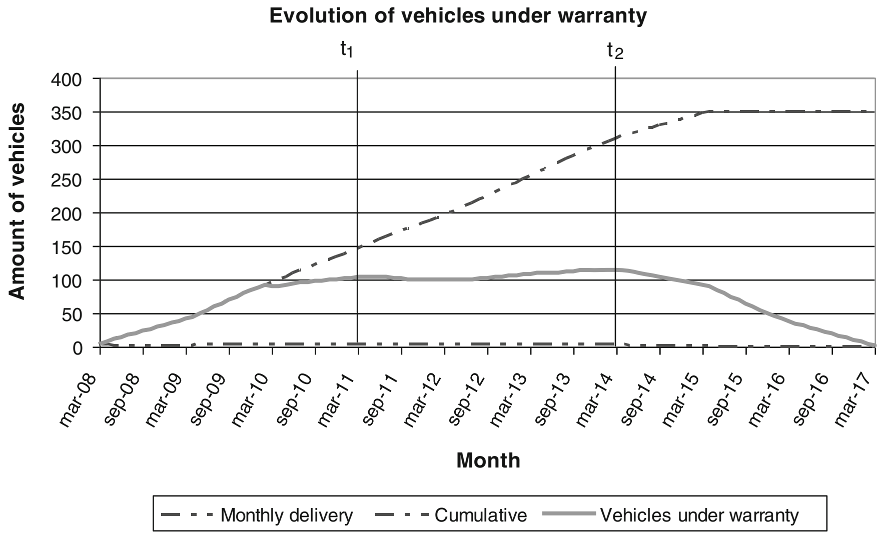

Fig. 2.3 Warranty evolution graphic, in terms of deliveries

necessary to bear the investment of a minimum strategical stock in mind in order not to leave warranty claims unattended.

Considering the data indicated above, it is possible to carry out a simple costs analysis obtaining some average values. Calculation of some values:

- Warranty cost per complaints:
  $C_C = C_1/R_1 = 1{,}000{,}000.00/1{,}200 = 833.33$ €

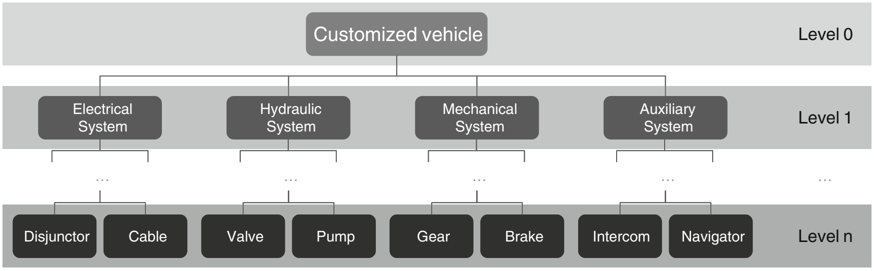

Fig. 2.4 Classification tree of components

- Warranty cost per vehicle:
  $C_V = C_1/V_1 = 1{,}000{,}000.00/150 = 6{,}666.67$ €
- Complaints per vehicle:
  $R_V = R_1/V_1 = 1{,}200/150 = 8$ complaints

With these values, and in order to illustrate them more clearly, a graphic (Fig. 2.5) is included in the warranty evolution in terms of costs. That is because the total incurred warranty cost of every vehicle has been considered in a conservative way. That means they have been treated as already incurred costs when each vehicle is delivered to the customer. Therefore, the accumulate warranty cost does not increase after the delivery of the last vehicle. In further studies, it will be possible to consider as well several destinations of the vehicles, where a maximum number of local vehicles can happen in different moments of the defined lifetime and costs must include the movement of warranty teams to different locations.

Comparing the above results with the foreseen costs indicated in the EAC, a graphic is obtained as the one set out in Fig. 2.5. The EAC is formed by a first part already known, which refers to the Incurred to Date (ITD), plus a second foreseen part (continuous gray line), which refers to the Estimate to Completion (ETC). Apart from the EAC line, the warranty cost line obtained from the cost average in t_1 is also here implemented (discontinuous black line). As a result from this graphic comparison, one can see that the cost at the end (ca. 2,335,000.00 €) is slightly lower than the budget considered at the beginning of the project (2,625,000.00 €). This means, there is a budgetary buffer of ca. 290,000.00 €, which can be used for the investment of a strategic stock of spare parts. This amount would correspond to the budget for attending the warranty of around 43 vehicles, or equivalent as if the warranty assistance should be taking the advantage of ca. 15 months before the end of the manufacturing process. Other interesting average values that can be obtained from this exercise are for example the estimated total amount of warranty claims, which shall be around 2,800 reclamations. Anyway, and as the main conclusion of this analysis, the procurement of these strategic spare parts should avoid the use of the stock shared with the assembly line, offering this way an appropriate service to the client. That is due to the possibility of assisting warranties independently of the manufacturing department and consequently, not affecting the final goal of the project.

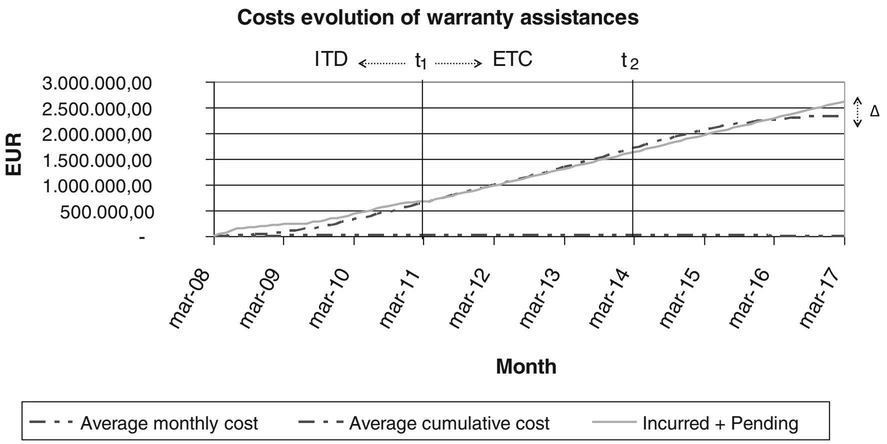

Fig. 2.5 EAC versus average cost line

2.3.2 Quantitative Analysis of the Claims

It has been possible to compile data for a large variety of items with customer complaints. These items are classified according to their functionality and also divided into components that can be procured (see Fig. 2.4: Classification tree of components). Fig. 2.6 exposes a sample of the gathered data as an example for this case study.

This kind of analysis usually helps not only the quality department, but also the manufacturing process, in order to focus on the components which have more incidents during the warranty period. By improving the manufacturing process or taking special care during the assembly of components, it is possible to reduce complaints regarding a specific item. Due to the large amount of components in complex systems such as an industrial customized vehicle, it is suggested to select the items to make all the gathered information easier to manipulate. The set of criteria to select a group of items is not exclusively related to the number of failure occurrences. The cost of such components is also important, as well as the delivery time to procure them, etc. In general, it is important to know how critical each component is for the company and for the fulfillment of the production line. All these features will be conditions to bear in mind when the time to make a decision comes. In other words, these features will be turned into factors which will give a specific weight to each component. This weight will finally help the manager to make the proper decision. By taking this into account, and referring back to the previous figures and data included in the graphic, it is possible to transform the data in terms of relative frequency. This relative frequency refers to the number (n_i) of times that an event (i) takes place (in our case, failures) and divided per the total number of events (Σn_i). Considering therefore statistical concepts (and together with other factors) is possible further on to weigh, as mentioned, the value

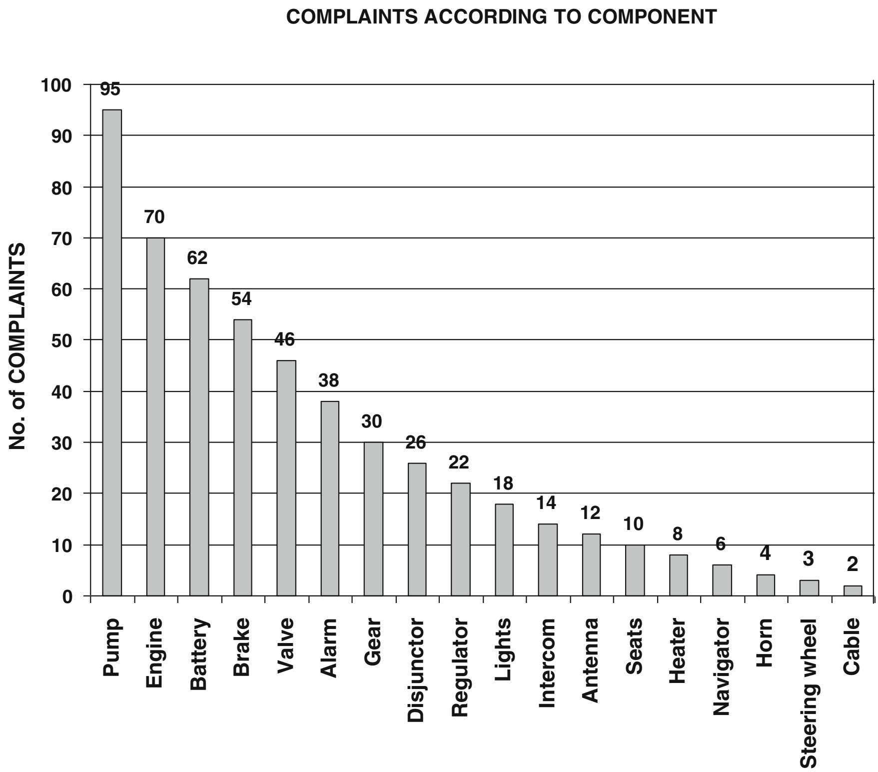

Fig. 2.6 Number of complaints per component

of each component in order to prioritize between the supplies for warranty assistance or to keep the available piece for the manufacturing process (Table 2.3).

A very interesting reference regarding analysis of data statistics is [10], where data analysis is used for the improvement of TQM. The rest of the components are basically not considered because:

- They have been affected by a very small number of failures.
- They have been delivered fast enough and mostly in time.
- There is extra stock in warehouse due to the purchasing of a minimum amount of pieces, greater than the real necessity.
- Or they are not, definitively, under the interest of the project managers' point of view, due to other reasons.

Summarizing, with the tasks previously explained in order to obtain a set of chosen components (those acknowledged as critical), what we are really composing is a list of strategical spare parts. This means that, in case the company approves the use of the budgetary buffer that supports of the warranty service, the purchasing process can be quickly launched. All these actions will finally lead the company to positive returns:

Table 2.3 Relative frequencies

Component	Number of claims	$f_i = n_i / \sum n_i$
Pump	95	0.1827
Engine	70	0.1346
Battery	62	0.1192
Brakes	54	0.1038
Valve	46	0.0885
Alarm	38	0.0731
Gear	30	0.0577
Disjunctor	26	0.05
Regulator	22	0.0423
Lights	18	0.0346
Intercom	14	0.0269
Antenna	12	0.0231
Seats	10	0.0192
Heater	8	0.0154
Navigator	6	0.0115
Horn	4	0.0077
Steering wheel	3	0.0058
Cable	2	0.0038

- By reducing the probability of paying penalties due to global delay in the project delivery.
- By improving the confidence of the client due to the completion of contractual terms, such as the warranty assistance.

It is necessary to remark that everyone of the failures referred so far are incidences considered to be under warranty. For further research in this field, incidences not considered under warranty are also included. The analysis of such events must take into account the reasons why these situations occur (bad training of the user?, poor information for maintenance?, clients accustomed to other family product with different behavior?, etc.). Anyway, in each case and even when the failure is not attributed to the manufacturer, the company must take interest in the possible causes.

2.3.3 Spare Parts Management for Warranty Assistance

Regarding logistics of warranty services, Ref. [11] discusses diverse questions in this context. The change in the utilization of pieces from assembly line to warranty assistance has a negative effect in terms of cost on the whole project. The extra costs associated with the spare parts are of course due to the different prices between the acquisition of a piece at the beginning of the project for the whole fleet, and the acquisition of a piece punctually during the lifetime of the project and for a specific incident. Therefore, management must provide compensation between the difference of values in order not to keep such increments in the total costs of manufacturing, but to incur in the total warranty costs.

Consequently, the percentage incremented in the final price of purchase can also be a factor to bear in mind when estimating the weight for each component. In order to ascertain a correct warranty support service, the proposed action is basically to acquire various reserves that would allow repairs without delays in the vehicle manufacturing and simultaneously during the process and to supply spares to the warranty service from the assembly line in a reasonable way. According to the aforementioned considerations, and together with the data collected, the experience of warranty/maintenance technicians, the knowledge of the engineering department, and of course using the already developed techniques in maintenance (Fig. 2.7), it is possible not only to elaborate a spare parts purchase plan for warranty, but also to improve the business decision-making process as well as to contribute with improvement actions for engineering and manufacturing. This purchase plan refers to an applicable list of essential parts to assure the satisfactory assistance of a large number of reclamations. At the end of the warranty period, the remaining spare parts can be negotiated with the client for their use in further maintenance tasks. This fact forces strict control of all these material parts so that they remain available for supply to the customer at the conclusion of the project. At the same time, this action will represent an opportunity to recuperate, at a determined point in the future, one part of the incurred cost. In general, decision-making will be the result of a process focused on a final choice among several alternatives. In our case, in order to lead the company to a fast and adequate decision-making process, every department should clearly identify what needs to be done and what is the scope of their responsibility. For the company in this case, we have adapted the idea of a warranty management system divided into modules, proposing furthermore, certain interactions among different departments within the company, which share the information, make suitable decisions according to their responsibilities, and coordinate activities to a common and profitable goal for the whole company. In order to illustrate such interactions, activities, etc., a workflow has been used (Figs. 2.8, 2.9) following a business process modeling notation (BPMN) methodology as a graphical representation for this specific business process, making it more easily understandable. The considered departments here (including the client) are as follows:

- Logistics department (LD)
- Manufacturing department (MD)
- Administration (MB)
- After-sales department (AD)
- Quality department (QD)
- Purchasing department (PD)
- Engineering department (ED)
- Customer (C).

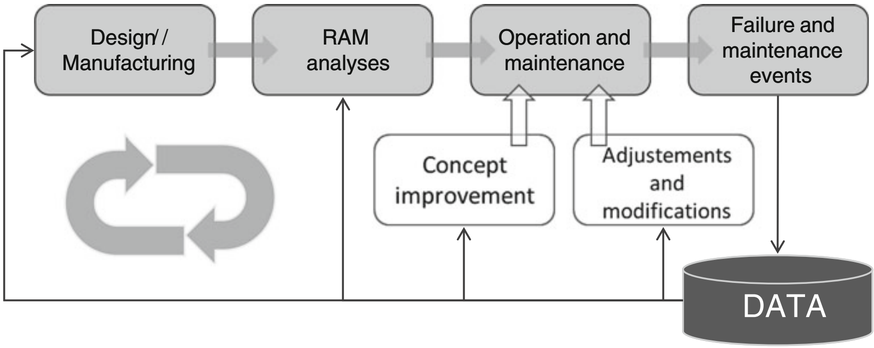

Fig. 2.7 Typical feedback from collected reliability and maintenance data

The process starts when the customer detects a failure in a vehicle and consequently informs the company. Communication can be addressed to different department of the company, but the most appropriate way is to channel them in only one communicator as, for example, the service or after-sales department. Anyway, the after-sales department can also detect failures in the course of its maintenance activities (see Fig. 2.8). In any case, once the information reaches the after-sales department, the facilitated information is analyzed. If the incidence is considered not to be object of repair under warranty (for example, when the cause of the failure has been a wrong or bad utilization), the after-sales department informs the management board who finally decides if, in spite of this, the incidence is repaired as warranty. If the incidence is discarded as warranty repair, the management board should also inform the customer. The customer can of course disagree with such a consideration. Therefore, a list of interventions (those not considered firstly as warranty) must be negotiated between the parts. If the incidence is considered under warranty conditions, the after-sales department must carry out a diagnosis of the incidence, detecting the problem, analyzing its solution, and determining the resources (staff and materials) and the necessary time for repair. In reference to the material, the warranty technicians must identify between the repairable and the non-reparable/consumable materials. In reference to the materials, warranty technicians must identify those repairable from those that are not or material for sale. The necessities in general are communicated to the company management who addresses the actions to the corresponding department (logistics, manufacturing, and/or purchasing department), in order to finally facilitate the material to the after-sales department. This is the moment when the company administration must make the most important decisions in terms of costs and manufacturing prevision. Once the after-sales department has the material (either by a loan from warehouse, by a loan by cannibalization, or acquisition by purchasing), they inform the management board (and afterward the client) (see Fig. 2.9) the subsequent action plans. The damaged material is sent to the company where the quality department (together in some cases with the engineering department) analyzes the failure. If the repair has been by replacement and the

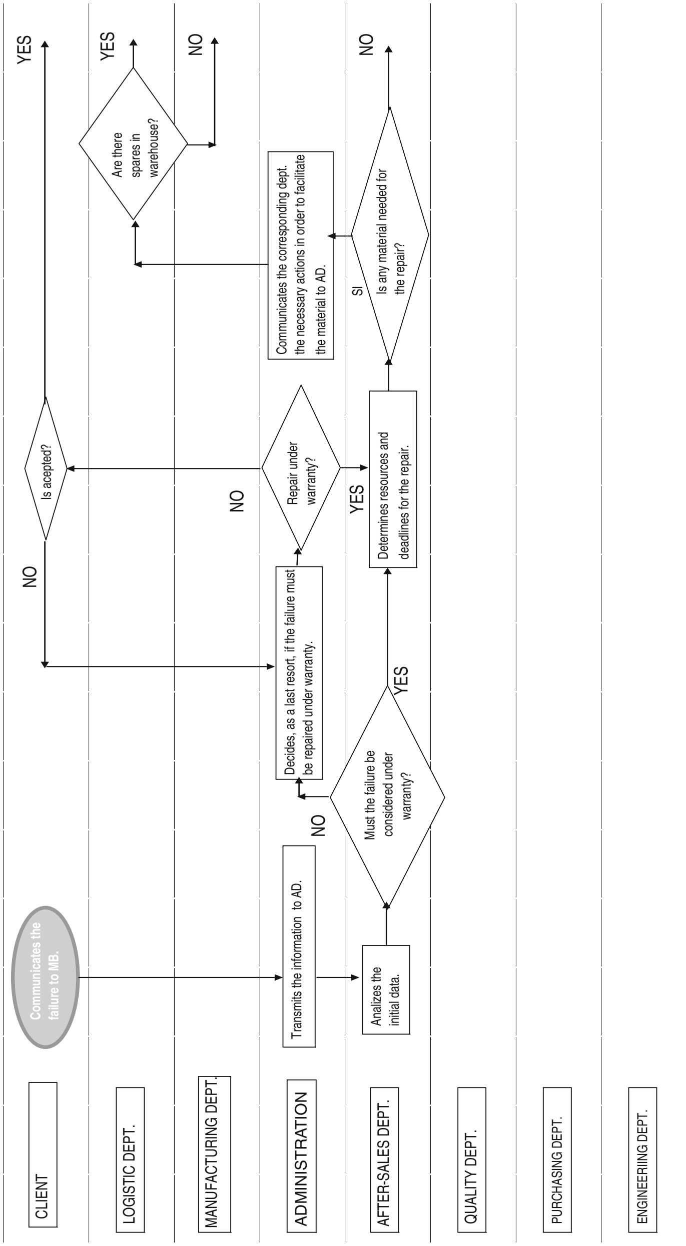

Fig. 2.8 Workflow of the warranty management process (part 1 of 2)

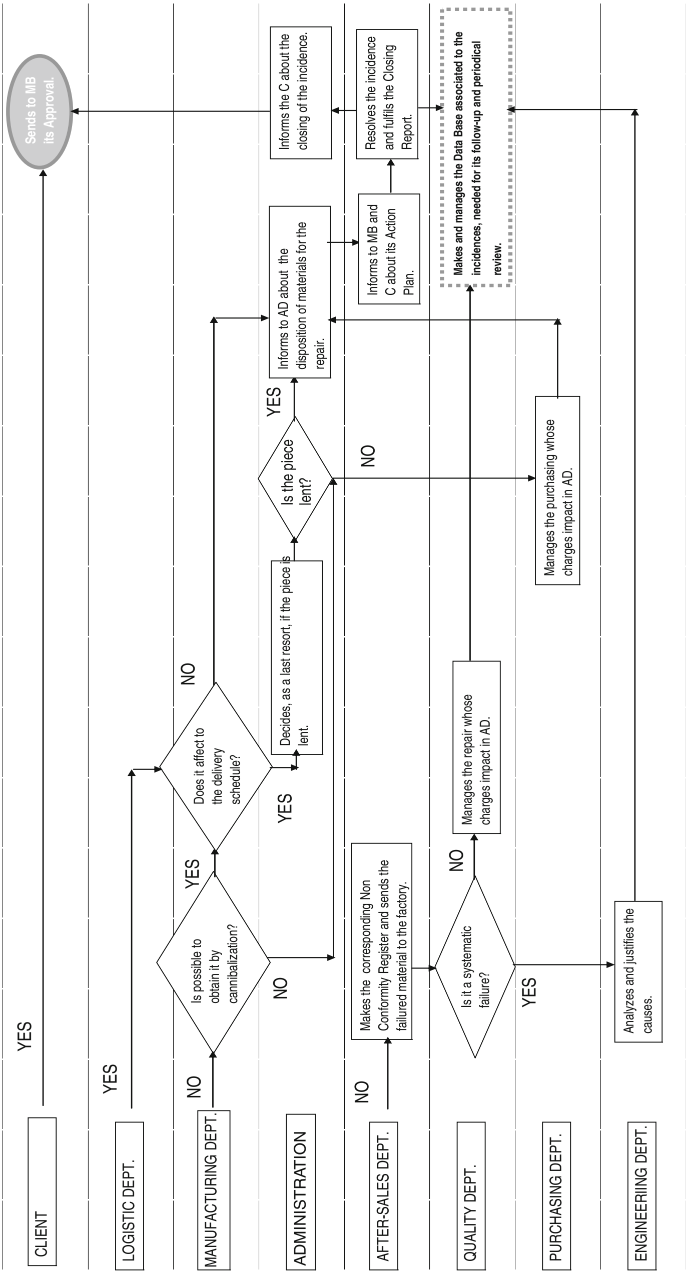

Fig. 2.9 Workflow of the warranty management process (part 2 of 2)

material is identified as repairable, the quality department manages the repair, taking into account the appropriate certification.

The material, once repaired and certificated, will be stored again in a warehouse for its usage in the assembly line. In this process, every piece of data about the incidence, damaged material, repair, etc., gathered by the after-sales, quality, and engineering departments are introduced in a database which is followed up and reviewed by the quality department. Once the incidence is resolved, the after-sales department communicates the closure of the assistance to the company administration, who transmits this to the client. It is important to receive a document from the customer with the approval of the performed tasks and the acceptance of the service closure. The database associated with these incidences and necessary for their follow-up and should include, not only those incidences considered to be under warranty, but also the data about preventive and corrective maintenance performed on every vehicle, in order to enable the analysis of, for example, repetitive or systematic failures among others studies. The described workflow refers to a particular management of a specific case study. This workflow does not intend to be generic and therefore is susceptible to improvement. It is proposed in Chap. 5 a general management with the aim of, later in Chap. 6, criticizing or evaluating the way management works. Likewise, in continuation to this chapter, it is suggested to consult Appendices 1 and 3, where matters such as quantification of maturity and analytical hierarchy processes are dealt with based on what it has been developed in this chapter.

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