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HANDLING OF IN-SERVICE SUPPORT: COMPARISON OF TWO CASE STUDIES FROM COMPLEX INDUSTRIES

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1. Introduction

In the last decade the service phase of a product's lifecycle has captured the attention of practitioners and researchers in the engineering design area. It has been widely acknowledged that the users determine the value of a product based on how the product is able to answer their day to day operational requirements over the life of the operation [Sakao and Shimomura 2007]. This is the underlying premise that has motivated academics to research Product-Service Systems and industry to move, from merely selling a product, to ensuring that the product would fulfil the user's needs.
Despite agreement on the importance of service, the definition of what service actually is varies from case to case and different approaches towards it have been adopted. Several research studies focus upon how to design services concurrently to products, or instead of products [Alonso-Rasgado and Thompson et al. 2004]. Other approaches focus upon how to support a product throughout its lifecycle in order to maintain or regain its functionalities [Long et al. 2009]. This latter is the approach towards service investigated in this paper.
Two companies, an aircraft manufacturer and a supplier of drilling systems for the oil industry, were selected as case studies. They supplied products and provided service throughout their lifecycle in the form of repair, training, maintenance, spare parts and overhaul. To facilitate the provision of in-service support, knowledge and information from past cases has to be used. Literature suggests that this can be achieved in multiple ways: by the reuse of documentation from previous cases, with knowledge managed through information and communication technologies [McMahon et al. 2004] or through personal communication within and across organizations, by, for example, building personal networks amongst employees [Wenger 2000]. Several research studies have been conducted to study how to use knowledge from previous cases to support current knowledge need. For instance, Aamodt et al. have proposed a model of reusing information from past cases based on (1) retrieve, (2) reuse, (3) revise and (4) retain [Aamodt and Plaza 1994]. However, this model merely focuses on the reuse of the solution adopted in previous cases, and does not consider how to reuse the knowledge related to the process followed to generate the solution. Reusing knowledge and information from service within the service phase of current and future products appears to be the most immediate way of taking advantage of experience from past cases, as it does not involve crossing organizational boundaries [Carlile 2004]. However, this is not systematically done in industry and it has only marginally been investigated in academic research. In fact, while a certain amount of research has investigated how to feed service information back to designers in order to improve the next generation of products, surprisingly little work has studied the specific expertise arising from servicing a product and how to transfer it within service to support service engineers while performing their work.

The purpose of this paper is to compare the strategy towards in-service support from contrasting sectors of industry through two case studies, focusing upon how knowledge generated during in-service support cases was reused within the service phase. A framework was proposed, which describes the ideal lifecycle of in-service information, and the two case studies were investigated against the framework in order to identify issues that posed a barrier to the systematic reuse of experience from past cases while providing in-service support.

2. Methods

A framework that represents the ideal lifecycle of information from service has been developed in order to analyse the case studies (see Figure 1). This framework focuses upon the importance of retaining information from past cases by updating existing knowledge, as suggested by research on case based reasoning [Aamodt and Plaza 1994]. However the research presented in this paper investigated not only the reuse of a solution, which is the main focus of case based reasoning, but also how the process followed to generate this solution could be reused across cases.
According to the proposed framework, the service practice is captured into documentation describing the case. Consequently this documentation is processed and, if possible, integrated into already existing documentation, in order to facilitate its application to other cases.

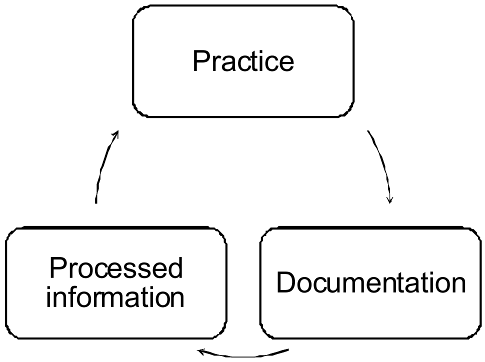

Figure 1. Framework of the lifecycle of knowledge from service used to analyse the two case studies

The two cases, described in detail in the following sections, were investigated through interviews with service engineers, analysis of the procedures related to the provision of in-service support and investigation of the information systems used to capture information about service cases. The data collected are summarised in Table 1.

Table 1. Data collected

	Interviews	Information systems	Procedures
Aircraft manufacturer	7	12	2
Supplier of drilling equipment	9	16	4

3. Supplier of drilling systems for the oil industry

3.1 Company background

The first case study analysed was a company supplying drilling systems for the oil industry. These systems covered the complete range of equipment necessary for an offshore oil rig to operate and were designed-to-order, based upon client's requirements. Most of the equipment was developed by modifying the standard design in order to take into account the characteristics of the rig (e.g. expected performances, lay-out, and size), the preferences of the client, and the expected field of operation. Due to the customised nature of the equipment, prototyping and testing were not part of the development phase. The equipment was developed in a linear manner without major iterations and tested only after being manufactured. Additional testing, to verify the functioning of the whole system and the various sub-systems in an operative context, was carried out during the commissioning phase of the rig.

3.1.1 In-service support provided

The company was involved throughout the entire lifecycle of the equipment: from developing the concept to supporting the operators during the service phase (e.g. providing maintenance, repair, training, overhaul, spare parts, upgrades). A dedicated department was established with full responsibility for supporting the equipment after it entered into service and included a customer support unit that represented the single point of contact between the company and the client for receiving any type of inquiry from the service phase.

3.2 Analysis against the framework

3.2.1 Processed information: procedures

A number of procedures, describing the workflows for different types of client's support, were developed through a top-down approach. Particularly, the procedure on how to handle a service intervention described the workflow to follow from the opening of a service inquiry to its closure, defined roles and responsibilities of the different stakeholders (customer support, service engineers, senior service engineers) and listed the documentation to generate. However it did not mention how to retrieve and reuse available documentation and how to evaluate and follow up a service intervention.
No standard solutions, directly applicable to recurrent cases, were available at the company.

3.2.2 Practice

The area of practice has been divided into three steps, these are dealt with below.

- Case identification

The customer support centre was the point of contact between the clients operating the equipment and the supplier. It received any service inquiry and forwarded it to the relevant section (spare parts, service, training, etc.) within the organization.
The customer support centre assigned every rig to a reference person that the client could contact directly when in need of support. This choice was motivated by the fact that the need of a person having a clear overview of a rig had higher priority than the need of standardising the in-service support provided. However, this personal approach toward service provision was in contrast with the company's objective of moving towards codification strategies, and resulted in difficulties in comparing cases managed by different people.

- Trouble shooting and implementation of the solution

Any service inquiry requiring a service intervention was addressed to a senior service engineer. He/she evaluated the case and assigned it to a service engineer that had to perform the service work on the rig. Alternatively, for minor interventions, the client was provided with instructions on the actions to perform to solve the case, or the requested spare parts were supplied.
While solving a service case, service engineers accessed information about past cases both by retrieving available documentation from the company's repositories and by contacting relevant people (i.e. the engineering designer responsible for the product or other service engineers). However, the customised nature of the equipment posed a barrier for searching for documentation across rigs, as it was difficult to assess similarities between cases without relying on personal experience. Documentation about the rig in question was used to obtain an overview of its history and the context in which the service engineer was going to operate, whilst experience from similar cases was reused thanks to communication among colleagues or personal knowledge. The difficulties in learning across cases by using available documentation were accentuated by not having a standard way to register a case. This made the access to past cases by memory or through the support of experienced people, acting as knowledge brokers, the most common way to retrieve documents.

- Closure of the case

Once the service intervention was completed, the service engineer wrote a report describing the work performed. The formal retrospective analysis of the case prescribed by the procedure was not always fulfilled (as visible from the notifications of changes, which frequently were not closed with the final approval).

3.2.3 Documentation

Both the capturing of information about a case into documentation and the retrieval of documentation from past cases to support the trouble shooting process were highly dependent on the individual performing the service intervention. Additionally, frequent changes to knowledge repositories hindered the retrieval of documentation from old cases, as the way to access information was dependent on when it was generated and how it was stored.

3.3 Overview

The following sections summarise barriers for the reuse of service knowledge elicited from the case study described above and indicate possible areas of improvement.

3.3.1 Barriers for the reuse of service knowledge

Despite the reuse of service knowledge from past cases during the trouble shooting process was dependent on the person interviewed; there was general agreement on the difficulties in obtaining valuable support from the available documentation. The reuse of experience from past service cases, whilst handling a new service case, was a process based on personalisation strategies, e.g. on the personal knowledge of past events from people covering senior positions and on communication among colleagues.
Figure 2 summarises the main issues that represented a barrier for the reuse of service knowledge from past cases while providing in-service support. Interestingly in this case there was now flow between documentation and the processed information (indicated by the cross in the figure). Additionally, documentation from service was directly used to support practice, thanks to the support of experienced engineers acting as knowledge brokers.

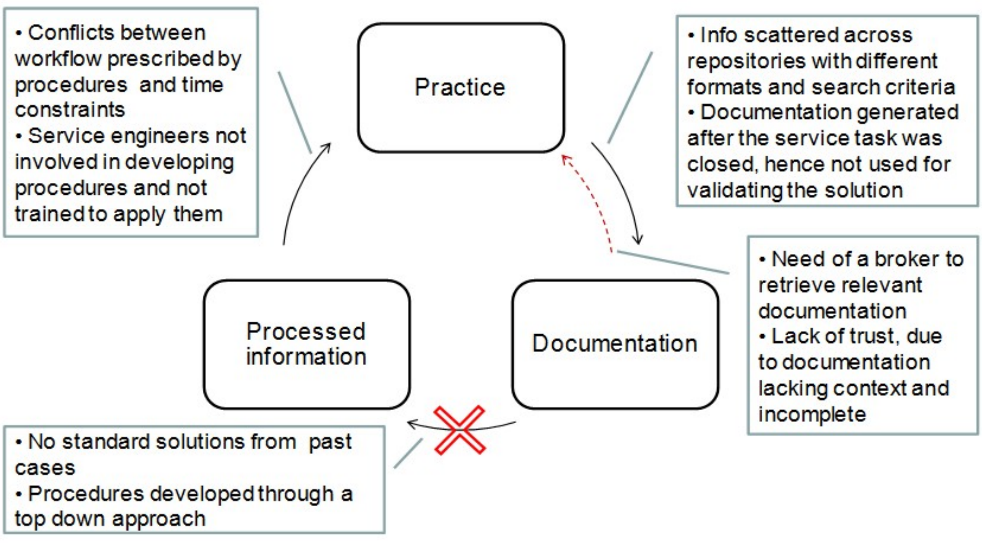

Figure 2. Barriers for the reuse of service knowledge for supplier of drilling systems

3.3.2 Areas of improvements

Factors that could improve the reuse of information from past cases as a form of support for service engineers while performing their job included:

- A better configuration of the company’s repositories, with documentation validated when the service case was closed and retrievable through a shared interface or, at least, using search criteria common across repositories.
- Grounding the company’s procedures into the service practice.
- Analysing service interventions in order to generate a set of standard cases.

4. Aircraft manufacturer

4.1 Company background

The second case study analysed was an aerospace company producing civilian and military aircrafts. The company developed and produced a wide range of aircraft models; the typical development cycle of a new model, from the early feasibility studies to testing and ramp-up, required about 15-20 years. The aircrafts were made-to-order, that means that their production was subsequent to receiving an order request from airline operators.

4.1.1 In-service support provided

The company had a central customer service department which acted as a focal point for all inquiries from airlines. These inquiries were forwarded to various sections within the in-service support departments, each dedicated to servicing specific parts of the aircraft.
The in-service support departments provide support on a 24-hour- a-day, 365-day-a-year basis to design and validate repairs requested by airlines. The repair requests were principally of two types:

- Major repairs, requiring significant support such as the direct involvement of a service engineer from the aircraft manufacturer in the repairing process.
- Simple repairs, resulting in providing the airline with repair instructions to implement usually by themselves.

Simple repairs represented the majority of the repair requests and were the main focus of the study presented in this paper.

4.2 Analysis against the framework

4.2.1 Processed information: procedures and standard solutions

An official procedure was available to describe the general in-service workflow. This procedure prescribed how to handle a service case, providing a high level workflow covering the whole process and instructions on how to generate and capture the outputs in specific steps. It did not include indications on how to retrieve and reuse past cases, despite this process being an important factor to ensure a quick response.
Besides the official procedure recognised at company level, one section of the service department also developed its own unofficial procedure, derived from the section's best practices for handling a service case, that described in detail the workflow for the part of the support where the section was involved.
In addition, standard repair manuals were made available by the company to provide instructions for generic repair. Many of these generic repair instructions were elicited by senior engineers based on their experience on recurrent cases.

4.2.2 Practice

The area of practice has been dealt with using for comparison the same three steps as in the oil drilling system case; they were in fact broadly the same.

- Case identification

The customer support centre was the point of contact for airline operators to raise in-service support request. It then forwarded these requests to the in-service department responsible for servicing the concerned part (wing, landing gear, fuselage, etc).

- Trouble shooting and implementation of the solution

The in-service department employed two types of service engineers: design repair engineers in charge of designing the repair method, and stress engineers in charge of validating the repair method. The two groups were managed respectively by senior design and senior stress engineers. When a repair request was received, the typical in-service support workflow included: (1) senior design and stress engineers assigning the task to respectively a design and a stress engineer; (2) the repair design engineer proposing a repair method for the reported damage; (3) the stress engineer validating the repair method with regard to stress and fatigue; (4) both senior design and stress engineers examining and eventually approving the repair method; and finally (5) the approved method being fed back to the customer service in the form of repair instructions, ready to be forwarded to the airline operator for implementation. The experience of engineers was highlighted as the most important factor for achieving a correct solution on time, as it influenced how to efficiently search for past cases and reuse the retrieved information in the most effective way.

- Closure of the service case

The operator, having implemented the solution, had to provide feedback to the aircraft manufacturer in order to receive formal approval of the repair work. After that, the service case was formally closed.

4.2.3 Documentation

Information related to tasks such as designing or validating a repair method was often scattered across repositories, and it required significant amount of time for service engineers to search for it. For this reason, both repair design and stress engineers relied on the indications included in the documentation from past cases for understanding what information was needed and where it was stored.

4.3 Overview

The following sections again summarise barriers for the reuse of service knowledge elicited from the case study described above and are subsequently used to compare the two cases in the next section.

4.3.1 Barriers for the reuse of service knowledge

The reuse of past experience, while defining the solution for a service case, was common practice at the collaborating company, as well as prescribed by both official procedure and best practice. However, several barriers for the systematic reuse of service knowledge were identified while investigating the case; the most significant are exemplified in Figure 3.

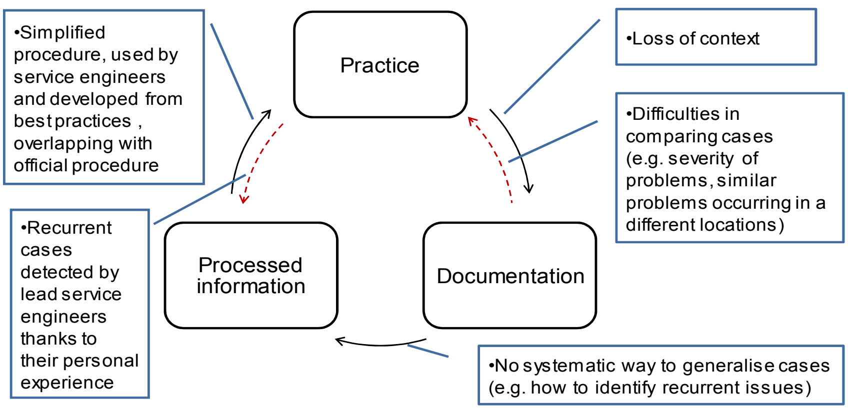

Figure 3. Barriers for the reuse of service knowledge in the case of the aircraft manufacturer

4.3.2 Areas of improvements

Hence, factors that could improve the reuse of information from past cases as a form of support for service engineers while performing their job included:

- Systematically summarising recurring repair cases. For example, using standardised methods to categorise repair cases and setting up regular meetings to review cases.
- Improving communication and inter-learning across in-service departments, and harmonise how official procedures are applied by different departments.
- Improving the repositories' search facility with focus on allowing comparisons between cases.
- Providing detailed guidelines on how to facilitate searching for information.

5. Comparison between cases

The analysis of the two case studies showed that both the companies were involved throughout the lifecycle of the products they developed by providing a similar type of in-service support (e.g.

maintenance, repairs, spare parts). However, their strategies towards the organisation of the in-service support provided and the reuse of information from past cases were divergent: the aircraft manufacturer adopted a more standardised approach, while the company supplying drilling systems was characterised by more personal approaches. These differences may have been motivated by diversities in:

- Product: more standardised in the case of an aircraft compared to a drilling system.
- Development process: the drilling equipment was designed-to-order according to the client's requirements and tested only after manufacturing, often under time constraints. On the contrary, the development of the aircraft was characterised by thorough testing in order to detect and correct any possible issue before the aircraft's ramp-up.

The fundamental differences between the two cases are summarised in Table 1 and described in the following sections.

Table 2. Differences between the two cases

		Aircraft	Drilling Systems
5.1	Type of in-service support provided	Service engineers provide remote support.	Service engineers are often sent on site.
5.2	Validation of solution	If predefined solutions are not applicable, the proposed solution has to be validated by stress engineer.	Validation from product responsible is not systematic and often follows the implementation of the solution.
5.3	Task allocation	Senior service engineer assigns a case to service engineer who suggests solution.	Senior service engineer supports service engineers during the service case.
5.4	Info and knowledge flow	Communication mediated by customer support both ways.	Direct contact between service engineers and client while providing the solution.
5.5	Level of codified documentation	Standard documents describing problem and solution.	Case documented according to type of case and people involved.
5.6	Reuse of past cases	Included in the standard workflow.	Not systematised.
5.7	Pre defined solutions	Available from the testing phase and past in-service cases.	Not available, a part from basic instructions from user manual.

5.1 Type of in-service support provided

Two types of service strategies have been elicited from the cases. The in-service support supplied by the aircraft manufacturer was generally characterised by relatively low variety, achieved by dividing the service department into sections dedicated to servicing a specific part of the aircraft. There was a highly formalised communication between aircraft manufacturer and airline and a systematic validation of the solution before its implementation. These characteristics allowed the choice of remote support as preferred type of in-service support and resulted in a reduction of the time required to handling a service case. However, necessary pre-requisites for the adoption of this type of strategy are the availability of the expertise needed to implement the solution outside the service department and a way of capturing service issues that provides service engineers with the information necessary for a correct evaluation of a case.

The organization of the in-service support at the supplier of drilling systems was different. The service cases were characterised by high variety – due to the customised nature of the drilling systems and the company's choice not to have service engineers specialised in servicing a specific type of equipment – and the support provided was based upon the dialogue between client and supplier during problem identification and the implementation of the solution. An increased level of remote support would result in advantages both in terms of time and costs. However, the company would need to follow a more systematic validation process before the implementation of the solution, as the current trial and error model would no longer be applicable, and problems in relation to the implementation of the solution may occur due to the lack of competent personnel on the rig. This latter issue could be addressed by designing the equipment according to principles that facilitate its service and maintenance, as suggested by methods like Design for Service or Design for Maintenance.

5.2 Validation of the solution

It was imperative for the aircraft manufacturer to implement an acceptable solution at first and no errors were allowed, in compliance with the strict regulations of the aerospace industry. This motivated the rigorous process of validating a repair solution before its implementation. Moreover, the adoption of a standard way of capturing information about a service case and transferring it between the service engineering department and the customer support resulted in positive effects such as:

- Systematic and consistent storing of service cases into knowledge repositories;
- Increasing trust in information available from the company's repositories, as it was validated before being stored.

On the contrary, most of the failures in the drilling equipment on an oil rig resulted in extremely high costs of downtime, but did not compromise the safety of the people on board. This meant trying to find a solution in the fastest possible way, that in most cases resulted in accessing information on past cases through personalisation strategies and elaborating the solution by trial and error through an iterative process. Moreover, as the supplier of drilling systems was directly involved in the implementation of the solution of a service case, the need of a detailed record of the work performed was less urgent than in the aerospace industry. However, there were some limitations of handling of service cases based on personal experience. Although it could lead to short term positive results, it was not beneficial in the long term, as it resulted in a non homogeneous quality of the service provided and in limited learning from past cases due to low quality and poor consistency of the available documentation.

5.3 Task allocation

The adoption of a standardised validation process allowed the aircraft manufacturer giving service engineers the responsibility for generating the solution in the form of repair method. In this context, senior service engineers covered mainly a managerial role and were responsible for following up service cases by developing e.g. standardised repair methods.

At the manufacturer of drilling systems, senior service engineers were actively involved in the progression of service cases by supporting service engineers while on site and providing them a description of the job to perform. This more active involvement of senior positions in providing in-service support was a manner to validate the decisions taken by service engineers without following a formal validation process.

5.4 Information and knowledge flow

In the case of the aircraft manufacturer, the customer support centre used to mediate the information flow between the company and its clients across the different phases of the in-service support. This organisational choice was motivated by the internal complexity of the company: the customer support had to coordinate the different sections of the service department and supply a standardised in-service support to the customers, no matter which part of the aircraft was involved.

In contrast, the supplier of drilling systems prioritised the provision of on-site support performed by a member of the service department. After receiving the service inquiry through the customer support centre, the approach towards service that was adopted was based upon the dialogue between the service engineer assigned to the case and the client, and did not generally include a formal validation process to be completed before implementing a solution.

Both cases pointed out difficulties of the customer support centre in performing a correct and consistent initial assessment of a new case. A preliminary retrieval of general information, linking possible technical solutions to costs, would be useful to support the initial choice of the type of support to provide (e.g. supplying spare parts or repair) and estimate time and costs required to solve the case.

5.5 Level of codified information

The organisation of the in-service support at the aircraft manufacturer, with the customer support centre responsible for mediating the communication between service engineers and the clients

throughout the different phases of the in-service support, required the use of a standardised way of handling service cases, particularly in respect to how to capture the documentation generated during the process and to provide the solution to the client.
The more personal approach towards service of the supplier of drilling systems limited the need of documentation while handling a service case and resulted in reports from service being completed only after the closure of the case, often not thoroughly and with poor consistency across cases. Both the cases showed issues related to capturing information of service cases, particularly:

- The way of capturing information changed throughout a product's lifecycle in term of both the type of information captured and where it was stored;
- Different repositories were available for storing information (e.g. drawings, emails, reports);
- The companies' procedures on how to generate and use documentation were general. Inconsistency emerged in how these procedures were interpreted by different sections.

5.6 Reuse of past cases

The reuse of past cases represented common practice and was included in the formal procedure describing the in-service support workflow at the aircraft manufacturer. However, the procedures did not include how to search for past cases. Past cases were reused in two distinguished manner:

- By reusing the solution already adopted in a previous case;
- By reusing the process followed to generate or validate the solution of a previous case.

The supplier of drilling systems reused past cases mainly through the personal experience of service engineers. When documentation from past cases was reused, it was retrieved by people already aware of the case or thanks to the suggestion from a colleague.
Both cases showed difficulties for service engineers to obtain useful information from available documentation, as it often included redundant information, not relevant beyond the specific case, and lacked information about context, important when comparing cases. Actually, a critical task was to assess relevance and similarities between cases in order to understand how experience from a past case could be reused while working on a new case. This problem was equally relevant for the two cases with respect to comparing issues, while it was more significant for the oil industry when it involved comparing products, due to the customised nature of the drilling equipment.

5.7 Pre-defined solutions

Predefined solutions, in the form of repair methods, were available to service engineers at the aerospace manufacturer. These standard solutions were developed from the analysis of recurrent past cases (see Figure 4). They allowed service engineers adopting an already validated solution when a service case was included in the range of cases covered by the predefined solution. Despite this strategy was used to transfer solutions across similar cases, it was not applicable for capturing commonly used processes and facilitating their application to new cases.
At the supplier of drilling equipment, processing information from service cases and generating standard solutions was not common practise. The only exception, when a solution applicable to a wide range of rigs was studied and distributed to the clients, was when a severe issue involving safety, health or environment occurred. In this case, all the rigs with similar equipment were informed and the actions, to prevent the occurrence of a similar issue, suggested. Figure 4 summarises the possible ways for reusing information from past cases.

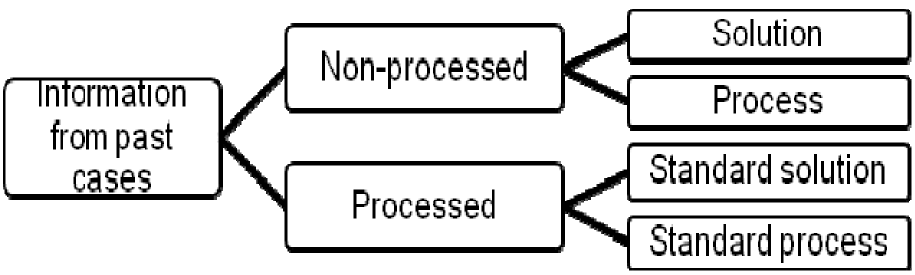

Figure 4. Ways to reuse service knowledge.

6. Conclusions

This paper illustrated and compared two case studies of companies developing complex products and servicing them throughout their lifecycle. The approaches adopted towards in-service support diverged. One company mainly provided remote support based upon a rigorous workflow that included the validation of a proposed solution before its implementation and a standardised communication flow between service engineers, customer service and clients. Documentation from past cases and standard repair instructions were systematically used to facilitate the process. Particularly, the available documentation was reused in two different ways: (1) to transfer the process that led to the identification or to the validation of a solution; (2) to transfer a solution.

The second company adopted a more personalised approach that relied to a great extent on the direct communication between the client and service engineers, frequently sent on site to implement the solution. This approach banked on the personal experience of service engineers and the support provided by senior positions informally validating the selected solution, and did not include a systematic reuse of documentation from past cases.

The main barriers for the reuse of service information that emerged from the two cases were mapped on a framework proposing the ideal lifecycle of information from service. The framework was based upon the distinction between documentation from single service cases and processed information (procedures, standard solutions) generated from the analysis of similar cases; the latter type of information being more effective to support service engineers while solving a service case. The barriers for the reuse of service information that emerged from the analysis included difficulties in assess similarities between cases and the lack of a standardised way to generate processed information. The validity of the results is still circumscribed due to the limited number of case studies taken into consideration. Nevertheless, the finding of this research can serve as input into more extended work which includes cases studies from (1) different service departments within the same company, (2) companies in the similar industries and (3) companies from different industries.

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