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Relating Information Technologies and knowledge in Submarines Construction

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1. Introduction

Applied scientists and engineers work for the Navy in technology development, in the design of certain critical components, to ensure safety and to determine the appropriate tradeoffs regarding performance, schedule, and cost. To carry out this work submarine engineers and designers must possess special knowledge beyond that required for building most other kinds of warships. Many systems must be designed for greater compactness and quietness than is needed for surface vessels, in this way, it is possible for these systems to resist the physical pressure of operations at sea. That is why the design process of a submarine is a task to integrate knowledge and complex technologies which must work simultaneously and which need the complement of the knowledge of the different agents related with the shipyard. In this work framework, the lack of suitable knowledge and experience of the staff could lead to an increase in construction costs due to changes or failure to adapt the uncompleted designs. Also, it has been consistently described the technology as a significant, powerful shift in the workplace climate, pedagogy and resulting learning (Davis, 2003).

Moreover, despite the fact that the Spanish Naval Industry invests time and resources in order to obtain certain knowledge, it takes an average time of 5 years to carry out controlled random tests. A great deal of this highly valuable knowledge gets lost due to several reasons, including, for example, either the lack of agreement between those who generate the knowledge, or staff rotations within the shipyards which make it impossible to obtain an overview of the construction process of a submarine, since people take fragments of that knowledge with them. In this situation, certain mechanisms must be developed in order to preserve knowledge in the Spanish Naval Industry and therefore to make it so that such knowledge can be reused for the local and global development of shipyard activities (Willcoks & Sauer, 2000).

On the other hand, when it comes down to knowledge preservation, it is necessary to speak about technologies and specifically about Information Technologies (IT). IT are mainly focused on acquiring and sharing information in order to create knowledge on the part of the user of the technological tool who interprets the information stored in that tool (Dewett & Jones, 2001). A good use of IT tools leads to better meeting the requirements of customers.

Considering the previous paragraphs, the aim of this paper is to analyse the knowledge learning process and systematisation used in the construction process of a conventional submarine. To do so, each building phase is analysed as well as the presence of IT in order to generate the required knowledge for each phase. The methodology followed consisted in 132 interviews to people linked to a naval shipyard. The most important contribution of the work is that it considers the different points of view of the different agents related with the shipyard (customers, suppliers, retired people, engineers and managers) on the usefulness of knowledge and IT which facilitate its creation and management.

In the next section, to help with the development of the research, the different conventional submarine construction phases and the process of learning required in the design and construction of a conventional submarine will be described.

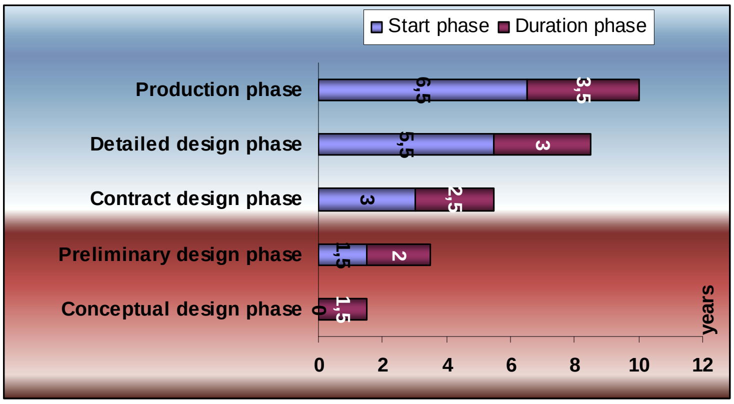
2. Learning in Submarine Design Program

The design process for a conventional submarine is exceedingly complex and requires a range of designers and engineers who possess not only the requisite technical knowledge, but also practical experience in submarine design. In order to reduce the probability of not obtaining enough knowledge or of gaining non-critical knowledge it is necessary for the shipyards to have suitable IT. It is only with the presence of these IT that the required mechanisms to obtain, keep and update knowledge from the different internal and external agents will be promoted. Also, it is important to be updated using IT, because for example, traditional mechanisms that support legitimacy, such as laws and customs are particularly ineffective in the cyberspace of today with its flexible, dynamic character, (Whitworth and de Moor, 2003). For example, different agents can be engaged in directed work relating to their own agenda. This has been successfully combined with collaborative discourse in computer-mediated conferencing through the use of cooperation scripts (Hron and Friedrich, 2003). In this context, the term "organizational learning" refers to the acquisition, distribution, interpretation and storage of knowledge which is essential for the organizational success of the shipyard (Huber, 1991). The above statements match those by Nevis et al (1995) when they say that all organizations are learning systems because they have processes and structures for the acquisition (where capacities and relationships are created and developed); distribution (where acquired knowledge is spread); interpretation and storage of knowledge (when knowledge is acquired and spread, the new knowledge is adapted to the working structure of the company).

Consequently, the performance of a shipyard is positively affected by the acquisition, distribution, interpretation, and storage of knowledge as long as the shipyard has already implemented IT for the creation of the so-called open organizational context. As shown in Figure 1 (own elaboration after interviewing and asking different shipyard agents about the project's progress and the deadline for completion of the conventional submarine) in order to design a conventional submarine, five phases are required: conceptual design phase, preliminary design phase, contract design phase, detailed design phase and production phase . Although all these phases require certain knowledge and are very important for the final design of the submarine, the learning mechanisms and the types of knowledge generated are different for each phase. The required learning mechanisms for each phase are specified in the following paragraphs.

During the Conceptual Design Phase the new submarine's purpose, principal operating and performance characteristics, and basic dimensions are defined. Initial estimates are developed for the cost of building the conceptual design. For this phase, the acquisition of knowledge is necessary. Furthermore, Cohen (1998) states that the new knowledge is not only acquired from outside the organization, but also from outside the reorganization of existing knowledge itself, within the organizational memory. Later on, initial exploratory researches give way to a Preliminary Design Development Phase, during this phase, future threats and missions are assessed and weighed up in relation to the availability of future technologies suitable for carrying out the required missions. It is obvious that a great deal of this information is also acquired by means of the collaboration of internal and external agents. For example, thanks to the collaboration of suppliers we can encourage, persuade, deal and learn about the future requirements and requests of current customers (the Spanish Navy) or potential ones (Navies from other countries) (Kaplan & Norton, 2000).

Figure 1. Design phases for first conventional submarine Source: Own Elaboration



In the Contract Design Phase, the top-level requirements are transformed into contract specifications for detailed design and construction of the submarine. Subsystems are defined, initial analyses and testing are completed, projected costs are established, and an initial set of ship specifications and contract drawings is prepared. A request for proposal is issued so the shipyard can respond and negotiate the price. In this phase the distribution of knowledge is essential, it is necessary to find some way of transferring the knowledge in the Spanish Naval Industry in order to make it available to external and internal members of the company. Failure to transfer the knowledge is likely to have a negative impact on the performance (Shane et al., 1995). For this reason, efficient and secure knowledge sharing is critical to the success of this third phase (Chen et al., 2001). After this, in the Detailed Design Phase, the shipyard initiates a phase in which the contract drawings and ship specifications of the contract design phase are transformed into the functional documents of the different installations and drawings necessary to construct, outfit, and test the submarine - with the interpretation of knowledge being a necessary factor. In order to review own and existing knowledge, IT tools facilitate the update and review of procedures, rules and processes in the Spanish Naval Industry. Moreover, the knowledge transfer and transformation processes previously described also make it easier. While transfer processes produce experiences at personal level, transformation processes allow the development of collective sources (Katz, 1982).

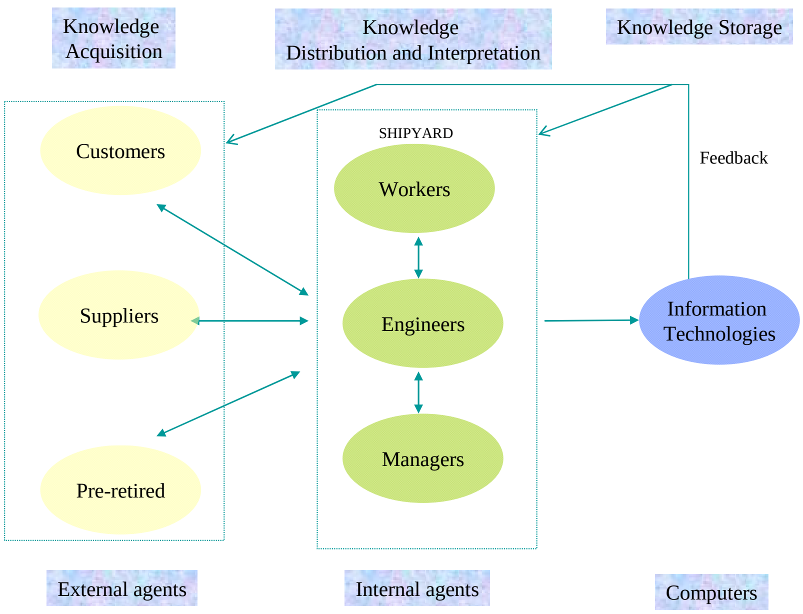
Finally, the Production Phase of the submarine starts before all drawings are complete. Production is limited by the drawings that are available, and changes to arrangements and specifications can lead to reworking during the construction process. In this phase, it is important to use the knowledge learnt, which should have been stored. The shipyard can use multiple tools to store knowledge and re-use it. However, the most used are IT (Arjonilla & Medina, 2002). IT also help this individual knowledge to be transformed into social knowledge, this transformation is due to a social process between groups and individuals (Nonaka & Takeuchi, 1995). The IT are a key factor which enables competitive advantage, by cementing relationships (Rambo & Beahler, 2003).

3. Method

In order to analyse the learning mechanisms during the construction process research into the different cases was carried out. The research was done between February 2008 and September 2010 coinciding with the final phase of the detailed design phase and the beginning of the production phase of the new submarine in construction for the Spanish Navy. According to that established by Yin (1994), the results were analysed by different authors independently and from different perspectives. Moreover, the shipyard of Cartagena has been chosen because it is important in the Spanish Naval Industry, with long experience in submarine construction and a leading shipyard in naval construction. Also, it must be highlighted that this shipyard is big and thanks to its commitment with innovation and technology has more than 1100 employees and it is the only shipyard in Spain dedicated to submarine construction.

To analyze Implementing Knowledge Practices and their impact on knowledge transfer, four weeks of interview sessions were conducted. 132 people were interviewed and participants were divided into six categories: customers, workers, managers, engineers, suppliers and retired or pre-retired workers. Customers, suppliers and retired or pre-retired workers belong to the external agents of the company and the workers, managers and engineers belong to the internal agents of the company. Interviews were semi-structured and conducted face-to-face. The interviews lasted between 35 and 50 minutes each. No interviews were taped, but extensive notes were taken during and after the interview and the interview notes were typewritten into protocols and coded, being divided accordingly into each category. Before the interviews, we asked the computing department and different leaders in the company who all confirmed to us the different IT tools used in the company and the different applications of the different tools.

Figure 2. Theoretical model



Source: Own Elaboration

Finally, considering the different design and construction phases in a conventional submarine and the stages of learning of acquiring, distributing, interpreting and storing knowledge; as well as the IT and the different agents related with the shipyard, our starting point was the model shown in Figure 2. This model begins with the process of acquiring the knowledge, since, in the conceptual design phase it is important that the shipyard knows what the clients want and need; in the preliminary design phase, the shipyard also needs to be in contact with the most important suppliers because there are specific installations for submarines in which there are between only 4 and 7 suppliers in the world, such as is the case for the system of hoistable masts, and therefore the shipyard needs to know the technology that the supplier offers. Moreover, the supplier knows the market because it has supplied other shipyards, and the shipyard should also make sure that the supplier is prepared to supply the shipyard. In addition, in this phase of acquiring knowledge, retired personnel are important because they contribute a great deal of theoretical and practical knowledge at the beginning of the design. After that we continue with the process of distributing and interpreting the knowledge, since, just as has been seen in the contract design and detailed design phases of the submarine, it is very important that the acquired knowledge is distributed and interpreted by the shipyard's agents; and efforts should be made to conserve it. The knowledge should be stored by means of IT so that it can be used correctly in the production phase.

In the model, the need for feedback of the knowledge by the different agents of the shipyard has been considered, for the Navy, because the Navy is the authority with the last word to approve the design of a submarine and is responsible for the engineering qualification of the completed product and all its sub-systems. Authority entails not only the technical acceptance of the design from a functional and safety point of view, but also the capacity of the design to meet the requirements of the program. Furthermore, the Navy is liable for guaranteeing that the finished product is fully tested and that it meets its own requirements. For this reason, the information exchange between the members of the shipyard and the Navy is essential and feedback is necessary in order to acquire the practical experience required for the building of the submarine. This is so for the suppliers, because during the design process and until the submarine is handed over, a technical harmony must exist to avoid future problems of integration and design of the equipment between the suppliers and the shipyard even in the smallest details. An example of this is what norms are employed by the shipyard with regard to the flange of the pipes to the different equipment of the submarine, since said norm should coincide with that used by the supplier in its equipment. This is important to ensure that no problem can arise in the future with regard to the integration between the supplier's equipment and the pipe incorporated by the shipyard, by the removal, because at certain moments of the design and production as well as for future improvements in subsequent submarines the experience is very valuable. Finally, the shipyard must provide feedback and share that information with the engineers and other members of the staff in charge of providing engineering knowledge necessary for the development and design improvement of the product (Chen et al., 2001).

To contrast the model, in-depth interviews were carried out to agents who were likely to have useful and valuable knowledge to be reused in future designs and constructions of the Spanish conventional submarine.

In this study, 12 different customers belonging to the main customer of the shipyard were interviewed; they did not declare any problem with the technical infrastructure of the company. However, they only had access to approximately 15% of the IT tools used by the shipyard. They affirmed that they would like to use more tools because although they have direct contact with members of the shipyard they could not see different designs and documents, and they also affirmed that although the Navy people evaluate different documentation received from the shipyard, they need more detailed information to help and give different ideas to the shipyard to improve the different designs and develop the equipment included in the vessels. Also, the Navy people manifested a favourable position to the use of IT after receiving the product, this means that by using IT they would be able to solve every type of problem and interchange knowledge with shipyard internal agents.

Also, forty-four workers belonging to different offices and workshops of the shipyard with more than 10 years experience working in the company were interviewed, and they emphasized the experience of the employees and the possibility of distribution and application of their knowledge in activities related with the organization. These ideas were attractive for them and motivating in order to learn how to use new tools and create new processes to develop their work. It is important to consider that an effective way to understand users of new technology is to use to the user in the following roles of the design process: as users, as testers, as informants and as design partners (Druin, 2002). Furthermore, the interviewed people highlighted that personal motivation was reinforced when they knew that the shipyard took into account their opinions and suggestions about acquiring external knowledge. On the other hand, some of the workers complained because only 20% of them had access to the different IT used by the shipyard. In their opinion, the lack of access to IT by all the workers was the reason for their unhappiness and the possible reason for the loss of knowledge. They suggested a suitable access to IT which would enable them to have a better interaction between them and the intermediate level engineers. Some underlined that this improvement would produce benefits for the rest of the shipyard because the relationship between departments would be improved.

It has not to forget, it is important to stress that in the Naval Industry the suppliers play an important role. Technology advances very rapidly and there are many installations which become obsolete in a short time such as, for example, Combat System equipment. Twenty-three suppliers of different companies were interviewed, ten of whom had worked with the shipyard on other projects previously. As with the customers, regarding the technical infrastructure of company, the suppliers declared that they have no problem, but complained that they could access only a few internal IT tools of the shipyard to be able to adapt their work to the philosophy of the company. Some of the suppliers of the shipyard mentioned the need to have greater access to the shipyard documentation (especially to technical specifications and standards used by the shipyard) since, like other examples, they mentioned that when they had to obtain a perfect coupling between a pipe connection provided by the shipyard and the flange that they provided, then standards or details used which differed from those used by the shipyard would cause losses sometimes to the supplier and sometimes to the shipyard itself.

At the same time, twenty-seven intermediate level engineers were interviewed who had been working a minimum of eight years in the shipyard, practically all of them had good technical infrastructure and access to 80% of the IT tools used by the company. Some of them could not have access to classified information or to information from other departments. But the real problem is that the intermediate level engineers emphasized that they did not have all the knowledge they wanted because a lot of subordinates did not have access to the IT used by the company.

But the most important, it was the interview to retired and pre-retired staff. Seventeen ex-workers of the shipyard were interviewed; they were between 59 and 68 years old. In the interview, we detected that retired and pre-retired people were unaware of the evolution of the technical infrastructure in the company from the time that they had left the company. We asked several retired and pre-retired workers about their availability to collaborate with the company (these people were pre-retired when between 52 and 55 years old during the last 13 years), 55% of them totally agreed to cooperate with the company and showed interest in receiving information about using different IT tools employed by the shipyard. The remaining 45 % did not want to know anything about the company because they want to have free time.

In the opinion of those interviewed, a great deal of their knowledge had not been transmitted to new generations in recent years because they had not had the opportunity to do so. Obviously this knowledge is important knowledge which has been lost by the company. As Srdoc et al., (1999) highlight, a retired person is able to make reliable calculations of a recurrent problem.

Finally, nine managers were interviewed belonging to different departments and they had worked a minimum of 20 years in the shipyard; managers had good technical infrastructure and access to all information and were an interface between intermediate level engineers and other managers of different departments. In our interviews, we discovered that they were aware of the fact that customers, suppliers, workers and retired workers hardly knew the different applications used by the shipyard and that the managers and engineers knew almost all the applications although they admitted that they did not use some of them. They also underlined that it was logical that the retired and pre-retired workers did not know the applications, especially because the evolution of the company in the past years had taken place at the same time as many of them had retired and IT were implemented. Table 1 includes a general summary of the results of the different interviews.

Table 1. Summary of the conclusions reached in the interviews

SUBJECT	CUSTOMER	WORKER	SUPPLIER	ENGINEER	RETIRED WORKERS	MANAGERS
Access to the technical infrastructure of the shipyard.	YES	YES	YES	YES	NO	YES
Access to IT tools used by the shipyard	YES [a]	YES [b]	NO	YES	NO	YES
Direct contact with members of the shipyard.	YES	YES	YES	YES	NO	YES

[a] Access to only 15% of IT tools
[b] Access to only 20% of IT tools

4. Discussion and Conclusions

Technical knowledge and practical experience are important assets in the design of a submarine, with the appropriate use of both we can prevent mistakes which would result in a great increase of the shipyard costs. But the problem with knowledge is that the person with the knowledge is the person who manages it, therefore an important contribution of the research is the model presented and the process proposed to codify knowledge which is individual when it is acquired by the people, and becomes social when it is distributed and utilised. On the other hand, in accordance with the 132 interviews, the use of IT allows reusing existing designs and achieving a higher efficiency in the performance of workers and engineers. These circumstances may lead to a reduction of working hours and work with quality technology for the next design. Also, thanks to the use of IT, the relationships with external agents of the company can be reinforced. Maybe that is why the Spanish shipyards are trying to improve their results by means of investments in information technologies. However, previous studies show that investment in IT is not associated to better business results (McGowan & Mady, 1998). On this matter, Chiasson and Lovato, (2001) suggest that the adoption of IT is a complex process that is influenced by numerous factors. Some of the factors mentioned include knowing what customers want and need, and fomenting the implementation of the process and organizational factors that promote IT use for different agents. Consequently, if the introduction and use of IT does not follow a lineal process in the model proposed, if, for example, it is poorly planned and developed, then the results obtained can be expected to be different.

In addition, this research has justified that an open learning context must promote the acquisition of knowledge from external agents to the shipyard. The later distribution and use of that knowledge among the members of the shipyard is promoted and facilitated by the use of IT. According to these results, the Spanish Naval Industry must redesign their IT tools taking into account the advice from internal and external members of the company because they both help and provide knowledge to it. A good use of IT increases the product and services complying with that stated by Dewett and Jones (2001) who state that: “the presence and good use of IT increase communication speed more accurately and facilitates the information communicated to be stored and classified easily and with lower costs”.

Another contribution obtained from this research is the relationship between knowledge codification and implemented information technologies. For this task the shipyard needs to acquire knowledge from external members and distribute and use it in the shipyard as per the previous steps. All those who have been interviewed agree with this statement. The relevance of this result is that it has to be distributed from the environment to the shipyard, allowing every community to make its own interpretation explicitly (Bonifacio et al., 2002). The results obtained confirm the opinion of Hsiu-Fen and Gwo-Guang (2005): they agree with the personal knowledge application circumstance that facilitates the workers to use the existing knowledge and to create new knowledge starting from codified knowledge. Both processes - codification and reutilization of knowledge- are necessary to adopt and are a good use of IT. The shipyard has to be more conscious of the benefits obtained in a working environment to implement IT (Gossain & Kandiah, 1998). By understanding how users perceive and use the IT of the shipyard, managers shall be able to design and implement a higher grade of utility of the systematized knowledge between their users.

In the case analyzed the results suggest that it is important to say that giving the customers and suppliers greater access to the IT tools used by the shipyard, then these groups would be more satisfied before, during and after receiving the products. Also, customers could help the company in the design, use, safety, trials, etc., of the different equipment. Ultimately, the customers are the operators of the final product and have a vision and knowledge which can execute the knowledge existent in the shipyard.

Interviews also suggest that a larger quantity of workers should have more access to the different IT tools used by the company and can participate in the use of IT tools. In this manner, intermediate level engineers could access the knowledge from workers to develop the work better and ensure a better knowledge transfer to other departments, managers, and external members of the company. Completing the above, it is necessary for the engineers to have tools such as laptops at home to have access to the IT tools of the company and so be able to coordinate professional and personal life. Another measure to apply could be the consideration of incentives for targets of codified and upgraded knowledge which can be applied to managers as well. With regard to retired and pre-retired workers it is necessary that they have direct contact with the different shipyard members; access to the shipyard infrastructure; and access to IT tools used by the shipyard; since the importance of both the codification as well as the reutilisation of the knowledge should not be forgotten. Only when the technologically advanced solutions are combined with the human creativity and the knowledge, will the shipyard be able to create a real competitive advantage in the market.

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