Making Sense of Knowledge Creation Processes: The case of a Greek Petrochemical Industry

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Ad Astra Per Aspera

(To the stars through inaccessible roads)

Abstract

This thesis is concerned with knowledge creation processes within service organizations, specifically in relation to the maintenance function. While bearing in mind the particular context of the study, the thesis argues that maintenance service work, when seen from such a knowledge creation perspective, affords important insights into the dynamic interrelations, links and social interactions within the knowledge creation processes themselves. To date, the knowledge management and organization studies literature tends not to treat these practical topics and theoretical issues in an integrated, holistic manner. The thesis addresses this lack using an in-depth, situated case study of the maintenance division of a major Greek petrochemical refinery.

The research adopts an interpretative perspective and makes sense of knowledge creation processes through the theoretical lens of the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001), combined with the knowledge activism framework (Von Krogh et al. 1997). Nonaka's framework, which guides data collection and analysis, suggests an approach to the investigation using the so-called SECI process. This process explains how knowledge creation unfolds, utilising the Japanese concept of Ba (which represents the process context), and the concept of knowledge assets (which corresponds to the process content). The explanation of important individual and group roles within knowledge creation processes using Von Krogh's framework integrates these concepts.

This use of a process view of knowledge creation helps explain a wide variety of complex and situated interrelations that demonstrate the existence of different modes of knowledge creation. Thus, the approach to process inquiry along with the research design fertilize methodological discussions about research on knowledge creation processes. The core theoretical contribution of the research concerns the provision of a process view of knowledge creation. Other theoretical implications of the research findings relate to insights on the complex nature of the knowledge creation process within a work environment, extensions to the research framework, and recommendations for further conceptual developments. The research also contributes practical implications and insights into, and specific conclusions about, knowledge creation processes and how they might be effectively managed in service organizations more generally.

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Table of Contents

Chapter 8 - Conclusions and Summary

List of figures

List of acronyms

AR	Asset Register
CMMS	Computerized Maintenance Management System
CWMS	Computerized Warehouse Management System
ED	Electrical Department
ICT	Information and Communication Technologies
ID	Instruments Department
IT	Information Technology
JP	Job Plan
MD	Maintenance Division
MWOS	Maintenance Work Order System
OD	Operations Division
PD	Planning Department
RED	Rotating Equipment Department
SED	Static Equipment Department
SSM	Soft Systems Methodology
TPM	Total Productive Maintenance
WD	Warehouse Department
WO	Work Order
WR	Work Request

Declaration

I declare that the thesis, excluding footnotes, is 109,600 words in length.

1

Taking the first step, An introduction to the journey

1.1 Background

The nature of knowledge, its origin and its veracity have been at the centre of philosophers' attention for centuries. We can go back to Plato (1993a) to find a widely accepted and influential definition of knowledge as a "justified true belief". Since then two existing epistemological traditions in philosophy concerning knowledge have developed. These are rationalism and empiricism. The debate between them has ebbed and flowed over the centuries, and latterly has influenced management thought. Descartes (1911), Kant (1965), Locke (1689) and Heidegger (1962), for example, have formulated arguments, published critiques and developed theories about these issues. The present study is not attempting to examine knowledge from such a philosophical perspective, however. "Such an understanding of knowledge was neither a determinant factor in building the knowledge-based theory of the firm nor in triggering researchers' and practitioners' interest in managing organizational knowledge" (Alavi and Leidner 2001: 108). Rather, this study concerns more contemporary issues of knowledge and knowledge creation processes, which, to a certain extent, have incorporated assumptions derived from the above-mentioned epistemological traditions.

The emergence of knowledge management in the 1990s resulted in the enrichment of the literature with a variety of concepts, such as the knowledge society and knowledge workers (Drucker 1993), knowledge strategy (Earl 1994c; 2001; Zack 1999a; Hansen et al. 1999), knowledge management processes (Nonaka 1994; 1995; 1998; Inkpen 1996; Inkpen and Dinur 1998), knowledge assets (Teece 1998; Boisot 1998; Nonaka et al. 2000b), knowledge stickiness (Szulanski 1996), communities of practice (Brown and Duguid 1991; 1998), intellectual capital (Nahapiet and Goshal 1998), knowledge markets (Davenport and Prusak 1998) and absorptive capacity (Cohen and Levinthal 1990). Despite the arguments that knowledge management is but another management fad or fashion (Alvesson and Karreman 2001; Scarbrough and Swan 2001; Galliers and Newell 2003), all this research has its foundations on the work of previous authors who, for example, drew attention to the importance of context-specific knowledge (Hayek 1945), pointed to the tacit dimension of knowledge (Polanyi 1946; 1962; 1966), argued that organizations learn and unlearn (Hedberg 1981), dealt with the issues of knowledge production and distribution (Machlup 1962; 1980; 1982; Gibbons et al. 1994), and presented a view of the firm as a repository of knowledge (Penrose 1959; Nelson and Winter 1982; Winter 1988).

However, both the economics and management literature have paid less attention to the process of knowledge creation, since they have tended to focus on aspects of knowledge accumulation and utilization. There are certain exceptions, of course: as the work of Von Krogh being an example (Von Krogh and Roos 1995b; Von Krogh et al. 2000b). Very often, this literature adopts a market perspective (Grover and Davenport 2001) - a transactional perspective, which assumes that knowledge exchanges occur in a marketplace (Davenport and Prusak 1998; Callon 1998; Boisot 1998; Teece 1998; Bukowitz and Williams 1999; Glazer 1998). Economic theories have treated knowledge, either implicitly or explicitly, as an important factor in economic phenomena, but have tended to "separate economic knowledge from the economic subject" (Nonaka and Takeuchi 1995: 35; Duguid 2005). However, Hayek (1945), in an attempt to describe the dynamics of economic change, argued that economic subjects possess context-specific knowledge. Penrose (1959) viewed firms as repositories of experience and explicit knowledge and argued about the conversion of tacit knowledge into explicit knowledge. In addition to these theories, neoclassical economics (Marshall 1965) and more recently, the evolutionary theory of economic change (Nelson and Winter 1977; 1982; Winter 1989), which also views the firm as a repository of knowledge in the form of skills, organizational routines and technological knowledge, tend to be silent as regards the knowledge-creating role of economic subjects. Further, they are less concerned with linking existing types of knowledge to broader organizational knowledge creation processes.

Similarly, management theories, despite their recognition of the importance of organizational knowledge, are mainly interested in the acquisition, accumulation, use and re-use of existing knowledge. Again, they have tended to neglect processes of new knowledge creation, with certain exceptions (e.g., Blackler 1995). Hence, Taylor (1911) focused primarily on explicit kinds of knowledge, while for Simon (1945; 1969; 1973), who introduced the concept of "bounded rationality" in building a theory of problem solving and decision-making, knowledge creation is essentially the outcome of information processing. In contrast, approaches that challenge the information-processing paradigm, such as Mayo (1949) and the "garbage can model" (Cohen et al. 1972; March and Olsen 1976), recognise the importance of socialization, tacit knowledge, ambiguity and creativity for the advancement of practical knowledge (Stehr 1992). They fail, nonetheless, to address the issue of knowledge creation in a holistic manner. In addition, studies of organizational culture (Pfeffer 1981; Peters and Waterman 1982; Schein 1985) "shed light on the organization as an epistemological system" (Nonaka and Takeuchi 1995: 42), but also neglect the role of individuals as knowledge creators and do not provide an integrated account of the creation of organizational knowledge. Furthermore, management and organization theories, since the mid-1980s, have pointed out the transition into the era of the "knowledge society" (Drucker 1993), explained the value-adding importance of knowledge work and skills, and explicated that knowledge becomes justified during action. Again, though, they fail to explain how individual knowledge becomes organizational knowledge. Moreover, it can also be argued that literature that deals with the building of a learning organization (Bateson 1973; Argyris and Schoen 1978; Hedberg 1981; Senge 1990a) lacks "the view that knowledge development constitutes learning" (Weick 1991: 122), since, according to the prevailing perspective, organizational learning is an adaptive change process. This has tended to present a barrier to theories concerning organizational learning to be associated with the process of knowledge creation[1]. Further, the resource-based (core-competence or core capability) approaches to strategic management (Prahalad and Hamel 1990; Stalk et al 1992; Teece et al. 2000), which accept that knowledge is merely another resource, tend to leave unexplained the processes for building organizational capabilities, notwithstanding the argument that these are processes of knowledge creation, as pointed out by Ciborra and Andreu (1996; 2000) and Zollo and Winter (2002).

However, this perceived gap in the literature is covered by a process-based perspective of knowledge management (Grover and Davenport 2001), which focuses on knowledge processes and on the context in which these processes are embedded (Nonaka 1994, 1995, 1998; Inkpen 1996; Inkpen and Dinur 1998; Alavi and Leidner 2001; Thompson and Walsham 2004). Such a process perspective recognizes that knowledge is interconnected to the process of its creation (Newell et al. 2002) and also shifts the focus of attention from knowledge itself to the process of knowing (Cook and Brown 1999; Orlikowski 2002). Within this perspective, and since the early 1990s, a number of frameworks (Nonaka 1994; Nonaka et al. 2001a; Spender 1996a; 1998; Blackler 1995) have been developed in an attempt to explain the process by which organizational knowledge is created, to enhance the understanding of the involved knowledge types within this process, and to explain the organizational conditions under which these knowledge types are created and applied (Robertson 1999; Newell et al. 2002).

[1] The creation of the Organizational Knowledge, Learning and Capabilities Conference – the first being held at the University of Warwick in 1999 – might be seen, in some ways, to overcome this barrier.

Of the three frameworks for knowledge creation processes (Nonaka 1994; Nonaka et al. 2001a; Spender 1996a; 1998; Blackler 1995) - which mainly adopt a structuralist perspective (Newell et al. 2002) on knowledge that accepts knowledge as an object - Nonaka's Model of Dynamic Knowledge Creation (Nonaka et al. 2001a) qualifies for research on processes of knowledge creation, not only as a driver of data collection, but also as a conceptual lens for their analysis (Walsham 1995b). An important reason for this is that the model embraces a definition of the term process (Van de Ven 1992) that accepts reality as being socially constructed and as a continuous and patterned sequence of events (Berger and Luckmann 1966; Abbott 1990; Pettigrew 1992; Van de Ven and Huber 1990; Shaw and Jarvenpaa 1997), giving explanation to the questions of how and why (Van de Ven 1992; Van de Ven and Poole 1995) the process of knowledge creation unfolds over time, and how organizational knowledge develops. In contrast, the other two frameworks (Spender 1996a; Blackler 1995; Blackler et al. 1998) tend to reduce the knowledge creation process to a set of types of knowledge, with relative neglect being given to the developmental nature and characteristics of this process. As a consequence, frameworks that adopt such an approach diminish the role of individuals and groups in the control, use and re-use of these pre-existing types of knowledge (Earl and Scott 1999; Bukowitz and Williams 1999; Ruggles 1998; Markus 2001).

The underpinnings of my research on knowledge creation processes are both simple and humble. An examination of the market and the process perspectives on knowledge management (Grover and Davenport 2001) reveals the adoption of the same or similar concepts associated with the content and context of knowledge creation. Hence, the concept of Ba, which is the context for knowledge creation (Nonaka 1998), is equivalent to the concept of Information-Space of the market perspective, within which the creation and diffusion of knowledge can be understood (Boisot 1995; 1998). Similarly, the concept of knowledge assets refers to the content of the knowledge creation process, from a process perspective (Nonaka et al. 2000b; Nonaka et al. 2001a), or to the outcome of knowledge production, from a market perspective (Boisot 1998; Teece 1998; Bukowitz and Williams 1999; Glazer 1998; Hassard and Keleman 2002). However, the literature, from both perspectives, fails to explain adequately and in an integrated manner not only knowledge creation as a social process, but also the interrelationships within this process with its context and its content. This is a similar argument to that of Walsham (1993), who addresses issues of context and content in processes of organizational change, and to that of Pettigrew (1987; 1992), who addresses the same issues in strategy process research. Thus, despite their quite recent introduction, concepts about the context and the content of knowledge creation processes, such as Ba and knowledge assets, gain ground in diverse streams of knowledge management as integral parts of these processes. This, in combination with the fact that recently literature started to emphasize the enabling role of individuals and groups within these social processes (Von Krogh et al. 1997; Von Krogh et al. 2000a; Ichijo et al. 1998), gives credence to the argument that research efforts that integrate these elements have a significant potential.

The following theme explicates the thesis aim and the investigative focus, before the description of the research contribution and the organization of the research.

1.2 Thesis aim and investigative focus

The complex nature of processes of knowledge creation suggests their interdependence with their context and their content. The point that these issues have concerned organizations and researchers alike provides the rationale for undertaking in-depth research that embraces them in a holistic manner. As we have seen, however, the knowledge management and organizational studies literature have failed for the most part to treat these topics and theoretical issues in an integrated manner. In fact, different disciplines tend to separate these issues into different spheres of interest, making difficult any reference to interrelationships. For example, while organizational studies deal with aspects of the knowledge creation process in cases of product development, they appear less concerned with the process content, or knowledge assets, which appears to be of greater interest in the field of economics. A review of the literature reveals that our understanding of the dynamics of knowledge creation processes remains underdeveloped and under-explored. Thus, the primary aim of the research presented in this thesis is to:

- Explain knowledge creation as a social process and interrelate it to its social and organizational context, and its content.

A second more specific research aim is to:

- Explain how individual and group actions and interactions influence these interrelationships.

The employment of an interpretative research approach allows for a thorough analysis - both retrospective and contemporary - of the development of the knowledge creation process, of the features, the conditions and the complexity of its organizational and social setting, which is often formed by social interactions, and of the process content. As such, this empirical research adopts a process perspective on knowledge creation (Grover and Davenport 2001).

1.3 Contribution of the research

The process of knowledge creation within service organizations is a distinctive example of the multiple interests and concerns of knowledge processes in organizations (Lowendahl et al. 2001). It is argued that maintenance service work, when seen from such a knowledge creation perspective affords important insights into the knowledge creation process itself and into the dynamic interrelations and links within the process, bearing in mind its context and its content. Insights are also afforded into the influence of social interactions that contribute to the shaping of the process context on these interrelations. This is attempted using the case of a professional maintenance service organization (Newell et al. 2002; Carlsen et al. 2004) and in particular the maintenance division of a major Greek petrochemical industry.

A basic assumption of my thesis is that in order to understand organizational knowledge (Tsoukas and Vladimirou 2001), which is often, tacit, collective, complex, contextual and rooted in culture, and the process of its creation, there is value in understanding work, and not in examining "knowledge resources or knowledge representations in isolation" (Carlsen et al. 2004: vii). It is in the context of work we understand the very process of organizational knowledge creation and whether the created knowledge, which is the content of this process, is valuable or applicable.

The selection of a professional maintenance service function for empirical research, approached via a knowledge creation process perspective, enhances the understanding of a type of work that differs markedly from other types of work, such as manual labour, or well-defined bureaucratic work (Lowendahl et al. 2001; Carlsen et al. 2004). Professional maintenance service work involves a highly educated workforce with expertise derived from specialized (Postrel 2002) and esoteric knowledge. This largely intangible resource base is also fundamentally distributed (Becker 2001) as knowledge resides in individuals and interactions amongst them. Additionally, maintenance work is to a large degree non-routinized and requires both analytic problem framing and solving. Much work is organized in projects that are unique to the situation, a unique constellation of personnel, objectives, approaches and division of labour. Furthermore, the deliverables of maintenance work are often intangibles in the form of non-standardized products and services, which create not only technical knowledge, bur also maintenance management knowledge - knowledge concerning the organizational capacity to act in other words (Stehr 1992).

The view of knowledge creation as a social process and its interrelation with the process context and content - the main focus of the research - are addressed in a number of different ways. First, they are addressed through a research design that makes an important methodological contribution. This contribution to interpretative research methodology relates to the necessity of an explanatory, case-based and interpretative approach to the holistic inquiry of the social process of knowledge creation. The research is one of a relatively few empirical studies that adopt an appropriate, and combined, framework in order to make sense of the knowledge creation process. Thus, the research makes sense of the knowledge creation process through the theoretical lens of the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a), which guides not only data collection, but also data analysis. Nonaka's framework suggests an approach to the investigative focus of the research through the concept of the SECI process, which explains how knowledge creation unfolds, through the concept of Ba (which represents the process context), and through the concept of knowledge assets (which corresponds to the process content).

However, while Nonaka's framework acknowledges the importance of the social context for knowledge creation, it is incapable of capturing social interaction. Hence, besides the use of Nonaka's framework, the investigation makes use of the knowledge activism framework (Von Krogh et al. 1997) with a view to explaining important individual and group roles within the knowledge creation process. This thesis does not simply repeat Von Krogh's (Von Krogh et al. 2000a) argument to focus on factors that enable knowledge creation, such as roles that shape the social context for this process. Rather, it demonstrates that the delineation of social interactions with Von Krogh's knowledge enabling roles acts as a connecting element for the concept of the SECI process, the concept of Ba, and the concept of knowledge assets, allowing the explanation of interrelations between these concepts. This sort of theory triangulation (Denzin 1978), which is achieved with the combined research framework, assists in capturing the process dimension of knowledge creation.

Another, secondary, methodological contribution lies in the fact that my research recognizes the need for making sense of the intangible knowledge assets within the knowledge creation process and its socialization stage. Therefore, a theoretical triangulation is also attempted with the use of frameworks for the explanation of trust (Newell et al. 2002), care (Von Krogh 1998), and the stages of socialization (Feldman 1976; 1981), and improvisation (Moorman and Miner 1998).

An additional methodological implication of my thesis, besides the adoption and utilization of the research framework, concerns the demonstration of how aspects of interpretative methods might be emphasized to accomplish research on knowledge processes. For example, the methodological contribution includes data source and methodological triangulation (Denzin

1978; Miles and Huberman 1994; Taylor and Bogdan 1998), which was attained through the adoption of multiple data collection methods for the production of various datasets.

The use of the combined framework in the thesis not only assists in explaining the complex and situated knowledge creation process, but also assists in proposing ideas and suggestions for the extension of the adopted research framework and its related concepts, achieving a multilevel theoretical contribution.

The research looked for knowledge-creating action and interaction in the analysis of the natural flow of maintenance works within the case organization, based on the knowledge creation episodes, as identified by Nonaka et al. (1994) in each stage of the SECI process. Hence, for example, the investigation explains how the transfer and accumulation of time- and space-specific tacit knowledge, mainly in the form of the experiential knowledge assets of skills, know-how and mental models and how the collection of internal and external information are involved in the socialization stage of knowledge creation. This approach can also be seen as a simple test of the knowledge creating episodes (Nonaka et al. 1994) within the context of the case organization.

However, the research moves one step forward, since it explains the continuity of the knowledge creation process by focusing on the links between the SECI process with the social and organizational context, and the involved knowledge assets. Hence, it shows how the four stages of the SECI process interconnect through the continuous flow of information, the evolution of knowledge assets and the actions and interactions of the process participants. The provision of insights about the continuity of the knowledge creation process identifies two-way links between the SECI process and the involved knowledge assets, the knowledge assets and the concept of Ba, and finally between the Ba and the SECI process. Some of these links are neglected by Nonaka's framework, as shown in the concluding chapter.

Moreover, the identified interrelationships between the three concepts are further clarified, since the research framework adopted succeeds in capturing and explaining the multi-dimensional character of the knowledge creation process by showing that each stage of the SECI process is an organizational, multi-actor, largely tacit routine (Nelson and Winter 1982; Cohen and Bacdayan 1994) consisting of many branches that are followed according to the prevailing circumstances. The organizational routine provides an aspect of the integration of the knowledge creation process with its context and content. This also provides an explanation for the coexistence of many different modes of the knowledge creation process within the same case organization.

Moreover, the provision of a process view of knowledge creation is achieved through the explanation of how knowledge assets are created and utilized by individuals and groups within each stage of the knowledge creation process. This represents a theoretical contribution in relation to the content of the knowledge creation process. The investigation shows that the knowledge assets are the inputs and outputs of the knowledge creation process, while it contributes to theoretical debates by explaining that they often moderate this process, either by influencing social interaction, or by regulating information flows in the SECI process. However, the research also points out the opposite relationship, in other words the influence of social interaction on knowledge assets.

Additionally, the research makes a contribution concerning the usefulness of the concept of knowledge activism (Von Krogh et al. 1997) in process research, since it provides insights into the shaping of the social context for knowledge creation. Thus, the framework explains social interactions that are neglected by Nonaka's framework. Its use also allows the delineation of the interrelationships of the social context with the information flows of the SECI process, and the development and use of knowledge assets. In addition, my thesis extends Von Krogh's framework by explaining that the knowledge activist roles can be performed by the same or by different individuals or groups, in a complementary or in a counterbalancing way. In the latter case, the performance of these roles does not always facilitate the knowledge creation process. Furthermore, the research also explains how various organizational conditions stimulate these patterns of interaction, and social interaction in general.

Besides the research contribution concerning the process view of knowledge creation, an additional theoretical contribution concerns the identification of two stages of knowledge justification within the knowledge creation process. The first stage justifies knowledge in reflection, while the second justifies knowledge in action.

Another important contribution concerns the explanation that the knowledge creation process justifies concurrently two kinds of knowledge. First, the process justifies the knowledge object per se, which in my case study is technical maintenance knowledge. Nevertheless, this kind of knowledge justification verifies (or sometimes rejects) the organizational capacity for action: the management and organizational route that was followed for the creation of the knowledge object.

Furthermore, the research provides specific insights into each stage of the knowledge creation process. For example, it suggests that socialization consists of various phases and explains their contribution to the knowledge creation process, such as in establishing communication channels and building two types of trust, companion and competence trust (Newell et al. 2002). It also demonstrates that the externalization stage is a reciprocal process of concept creation and rejection.

The research also suggests the idea for a distinction of the experiential knowledge assets into positive and negative ones, as a potential explanation for their moderating influence on the knowledge creation process.

In addition to these theoretical discussions, the research makes a practical contribution, mainly through the provision of insights and specific conclusions about the knowledge creation process and its management. For example, it indicates how the organizational structure and the workload influence knowledge creation. It demonstrates the importance of job rotation, ICT and a knowledge vision, and it explains that only those employees who have reached the advanced beginner stage of skill acquisition (Dreyfus and Dreyfus 1986) are actively involved within the knowledge creation process.

In addition, the research explains the impact of urgency on the knowledge creation process, it provides reasons that foster individual commitment in the process, and it indicates that technological discontinuities are important for the realization of requisite variety (Ashby 1957). Furthermore, the thesis explains the role of job rotation in realizing information redundancy and for building trust. It also gives reasons that obstruct individual and team autonomy, reducing the opportunities for accessing and utilizing valuable knowledge, and for framing problems.

Another practical insight concerns the contribution of various management levels to the performance of the knowledge activist roles. Hence, for example, it is shown how participants from various management levels develop and manage knowledge assets, either consciously or unconsciously. Conclusions are also drawn by examining the role of the middle management in combination to the role of lower management.

The practical implications of the research also include the relevance of my thesis to other settings. The findings of this investigation can be extrapolated not only to other maintenance service work organizations, but also other project-based organizations. Nevertheless, caution is required for the identification of organizational, social and infrastructure differences between my case organization and any organization to which these results might be transferred.

These practical implications are important especially in cases in which knowledge creation emerges somehow unconsciously, or even subconsciously, through the daily activities of participants rather than in a situation where management is trying consciously to direct the creation, capturing and utilization of knowledge. Thus, practitioners and management could benefit from a reflection on the practical insights and specific conclusions provided by the thesis in order to take advantage of the potential benefits and create new knowledge in the form of applicable and valuable knowledge assets. Hence, for example, these insights and specific conclusions could assist in the creation of job rotation for the transferring of the skills to employees, or even organizational restructuring initiatives, which might introduce new positions that would facilitate knowledge creation.

Figure 1.1 summarizes and presents the threefold contribution of the present thesis.

Figure 1.1 **Thesis Contribution**

Methodological Contribution
Approach to process inquiry & research design

Findings with:

Theoretical Contribution
- Process view of knowledge creation (Core Contribution)
- Nature of the knowledge creation process
- Extension of the research framework
- Suggestions for conceptual developments

Practical Contribution
- Management of the knowledge creation process

1.4 Thesis organization

An overview of this investigation is presented in Figure 1.2 and elaborated upon in chapters two to eight. **Chapter two** presents the research framework adopted and reviews and critiques literature from the fields of organizational studies, knowledge management, and knowledge processes in an attempt to position the research framework within the broader literature and to map associated debates, issues and research gaps.

More specifically, along with the definition of knowledge adopted the chapter discusses alternative perspectives and typologies of knowledge and explicates that the research uses the tacit/explicit knowledge epistemology. Then, amongst frameworks (Spender 1996a, 1998; Blackler 1995; Nonaka 1994) that deal with processes of knowledge creation and they adopt a structuralist perspective on knowledge (Newell et al. 2002), the chapter depicts and describes Nonaka's framework (Nonaka 1991; 1994; Nonaka and Takeuchi 1995) arguing for its suitability in providing a holistic perspective of this process in comparison to others. The Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a), which constitutes the most recent and integrated version of Nonaka's framework, not only explains how processes of knowledge creation develop, through the SECI process, but also interrelates them with their context and their content, through the concepts of Ba and knowledge assets, respectively. Having explained that this framework addresses the elements of the knowledge creation process that concern the research objective, a discussion concerning these three elements follows starting with the SECI process. The chapter points out that little empirical research has been conducted in relation to the framework's three constituting elements (Lessem and Palsule 1999), which had previously been examined separately, and that the literature lacks holistic empirical research that explains their interrelationships.

Then, chapter two presents the taxonomy of Ba that the present research uses for the investigation of the knowledge creation process context. Moreover, the chapter explains that the research is also concerned with the contribution of individual and group roles in the shaping of the social context. Therefore, it introduces the knowledge activism framework (Von Krogh et al. 1997), which is utilized in the present thesis for the interpretation of these roles. Moreover, my thesis is concerned with some organizational conditions that contribute to the building and energizing of the knowledge creation context by influencing its social interactions. These conditions are autonomy, creative chaos, information redundancy, requisite variety and care, trust and commitment.

Chapter two goes on to explain that the investigation approaches the issue of process content based on the concept of knowledge assets (Nonaka et al. 2001a). Thus, it explicates the kinds of knowledge assets and how these are involved in the present research, and brings forward the issue of their development and management.

Finally, the chapter explains that the investigation attempts to address some aspects of the management of the knowledge creation process within the case organization, to present the supporting infrastructure of this social process and make sense of the role of the knowledge vision in its direction.

Having established the need for an integrated explanation of knowledge creation processes, **chapter three** looks more deeply into the underpinning philosophical and methodological assumptions of the investigation and describes in detail aspects of the research design and analysis. It also suggests that an approach to inquiry, which is explanatory, case-based and interpretative, is appropriate for this study. Recognizing the need for the alignment between the research objectives, the theoretical foundations and the adopted methods of the research (Robey 1996), the chapter discusses some key aspects of the investigative focus that influence both the research assumptions and the investigative approach. Hence, this chapter explicates the adopted definition of the term "process" (Van de Ven 1992) and describes the nature of the knowledge creation process inquiry on the assumption that there is value in adopting such a process perspective for the investigative focus. It goes on to argue that an interpretative philosophical and methodological approach (Chua 1986) rooted in phenomenology (Boland 1979; 1985; Schwandt 2000; Gubrium and Hostein 2000) is in accordance with the investigative focus and the adopted definition of process, in contrast to more positivist and critical approaches. The main contributing reasons for the choice of interpretivism as a suitable approach within this research include the role of the researcher that cannot assume a neutral stance (Orlikowski and Baroudi 1991) and the use of theory (Eisenhardt 1989). Thus, the thesis uses the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a) not only as a guide to data collection, but also as the primary lens through which collected data are interpreted (Orlikowski 1993; Walsham 1993; Eisenhardt 1989). The fact that this model adopts a constructionist perspective (Berger and Luckmann 1966; Gergen 1999) and a definition of knowledge as "justified true belief", which categorizes it to the interpretative sociological paradigm that is concerned with the social construction of reality (Burrell and Morgan 1979), leads also to the adoption of an interpretative stance.

Following, and having established the need for the adoption of an interpretative approach, the chapter argues for the appropriateness of a case research strategy (Benbasat et al. 1987). Such a strategy allows the researcher to study context-specific knowledge creation processes in their natural setting (Benbasat et al. 1987; Luthans and Davis 1982). It also allows answering "how" and "why" questions, thereby facilitating the understanding about both the nature and complexity of various processes (Benbasat et al. 1987; Yin 1984; Eisenhardt 1989; Shanks 1997; Tsoukas 1989), and providing the opportunity for a holistic view of processes (Gummesson 1991; Lincoln and Guba 2000). Moreover, the selection of a case research strategy gives the opportunity for the gaining of insights from a different cultural perspective from a southern European country (Greece) (Benbasat et al. 1987) and a case organization with a pioneer position in its sector, the Athens oil refinery of Petrochem (fictional name) and its Maintenance Division (MD).

The rest of the chapter introduces the investigative approach starting with the selection of the case organization and discusses the issue of negotiating and obtaining access. Moreover, the role of the researcher, which is also combined with the role of consultant - something common in information systems research (Gummesson 1991; Zuboff 1988), since it facilitates increased access - along with the researcher's skills and background, initiate reflections concerning their interrelation with the research design. Thereby, it is argued that the researcher acquires at least a basic level of preunderstanding (Gummesson 1991) that allows him to understand the established technology and the organizational and social setting, while his knowledge of both the national and the technical language improve the chances of a richer interpretation of the maintenance knowledge creation process.

Chapter three goes on to describe the various collected datasets and their role in the research. The employment of multiple data collection methods aims at obtaining a rich set of data surrounding the knowledge creation process and at capturing its contextual complexity (Benbasat et al. 1987; Benbasat and Weber 1996). Moreover, the use of multiple data collection methods allows a kind of data source and methodological triangulation (Denzin 1978; Miles and Huberman 1994; Taylor and Bogdan 1998). Hence, the set of the collected data comprises semi-structured interviews, which are important in interpretative case studies (Walsham 1995b; Taylor and Bogdan 1998; Fontana and Frey 2000), documentation, archival records, direct and participant observation (Yin 1984). These datasets were obtained through a combination of multiple sampling strategies (Burgess 1984; Lee et al. 1991; Miles and Huberman 1994; Arbnor and Bjerke 1997), which intended to ensure their representativeness, to facilitate comparisons and to provide an information rich case.

The chapter then describes the establishment of rapport with case organization actors and details data collection procedures and their principles (Yin 1984), which contributed to the reduction of common qualitative research biases (Miles and Huberman 1994; Klein and Myers 1999), during the two main data collection periods.

The adopted data analysis strategy is also an important concern of chapter three. The research uses a combination of general analytic strategies (Yin 1984; Arbnor and Bjerke 1997) that guides the analysis relying on the expressed research questions (Yin 1984) with the support from a developed case description. In particular, the research adopts a special type of pattern-matching strategy, the explanation-building mode of analysis, which also contains some elements of chronological analysis (Yin 1984). Besides the use of Nonaka's framework (Nonaka et al. 2001a), such an analysis interprets the case by making use of the knowledge activism framework (Von Krogh et al. 1997) for the delineation of individual or group action and interaction.

Finally, and after a brief presentation of the unit of the analysis, which is the MD of Petrochem, the chapter concludes with some reflections on the quality of the research conclusions based on Yin's (1984) criteria for case studies.

Having established in chapter three the nature of process inquiry and the investigating approach used to make sense of the knowledge creation processes, **chapter four** is the first of a series of three chapters that present the data collected. This chapter introduces the case organization. The description focuses on basic aspects of the organizational structure and work, in particular the business and project layers (Nonaka 1994; Ekstedt et al. 1999), between which the knowledge creation process unfolds.

The description of the business layer starts with an overview and brief history of Petrochem that points out its public nature. Then, the chapter describes the educational profile and training policy of the organization as rough indicators of the quality of the business layer. Following, the presentation of the existing staffing procedures explains how the business layer is renewed. Then, the business layer description continues with a brief presentation of the technologically complex venues of the flagship of Petrochem, refinery A, focusing in particular on the bureaucratic and hierarchical departments of the MD, which are the main actors of the knowledge creation process examined in the present thesis.

Afterwards, the chapter deals with the maintenance workload, since it is one of the primary driving forces of knowledge creation, differentiating between the proactive and reactive approaches being adopted.

Finally, and besides the business and the project layers of the case organization, the chapter deals with two aspects of the organizational knowledge base (Nonaka 1994) that set the background for the development of an understanding of the maintenance knowledge creation process. It describes elements of the Computerized Maintenance Management System (CMMS) and the other maintenance-related software applications and goes on to delineate some important cultural elements and culture embedding, articulation and reinforcement mechanisms (Schein 1985) within Petrochem and the MD.

Having established in chapter four the background for the knowledge creation process, **chapter five** attempts to describe aspects of the organizational conditions and the knowledge vision

(Nonaka et al. 2001a) at the MD that stimulate and direct individual and group actions and interactions within a knowledge creation process. Thus, chapter five describes care (Von Krogh 1998) and trust (Newell et al. 2002) relationships at the MD and presents some reasons that foster individual commitment (Blau et al. 1993; Kalleberg et al. 1996; Price 1997). The chapter is concerned with autonomous action (Mainz et al. 1990; Owens 1991; Daft 1995; Newell et al. 2002) and pays particular attention to the operation of autonomous and self-organizing teams (Varela 1984; Nonaka 1994). Autonomy is important in knowledge creation processes, since it allows employees to frame a problem and then proceed to its resolution. An additional condition examined in chapter five concerns that of creative chaos (Nonaka 1988a; 1994; Senge 1990b; Leonard 1998) that stimulates interactions through the creation of a sense of crisis. Furthermore, another chapter theme deals with the realization of information redundancy (Dretske 1981; Nonaka 1990; 1994; Baumard 1999; Von Krogh and Kameny 2002) within the organization. In addition, the chapter focuses on the condition of requisite variety (Ashby 1957; Beer 1985; Kogut and Zander 1992; Nonaka and Takeuchi 1995), which achieves coherence and organizational adaptation to environmental changes. Finally, it concludes with a description of the existing equivocal vision that directs knowledge creation (Von Krogh et al. 2000a).

Having described in chapters four and five both the case organization and the general organizational conditions for knowledge creation, **chapter six** narrates the story of maintenance service work at the MD. Descriptions enriched with context-specific information also accompany the narration of episodes of the everyday maintenance working life, while emphasis is given to the roles of middle and lower management maintenance employees.

Thus, the chapter deals with the acquisition of maintenance skills, with the transfer of information and with information collection both from within or outside the MD. Moreover, this theme is also concerned with the deliberate or spontaneous interactions that facilitate these processes. The theme describes the skill acquisition process for various maintenance hierarchical levels, while it also provides characteristic examples of information collection, such as the everyday personnel meetings and the role and contribution of the union. In doing so, chapter six surfaces face-to-face interactions and links them with care (Von Krogh 1998) and trust (Newell et al. 2002) relationships, and with the concept of improvisation (Ciborra 1997; 1999a; 1999b; Weick 1998; Moorman and Miner 1998). Then, the chapter explains how maintenance personnel use acquired skills and know-how in order to formulate hypotheses about equipment faults and to build preventive and reactive maintenance repair concepts. The chapter then focuses on the planning and scheduling process of maintenance works through the story of the maintenance Job Plan. Finally, the chapter ends with a description of the execution of maintenance repairs, which often require experimentation and simulation. The narration explains that the multi-actor job execution routine has two fundamentally different branches, a preventive and a reactive maintenance branch, which are usually combined with relevant subcultures.

Chapter seven makes an attempt to make sense of the empirical data based on the theoretical framework that combines Nonaka's Unified Model of Dynamic Knowledge Creation with the knowledge activism framework for the delineation of important roles for knowledge creation (Von Krogh et al. 1997). The analysis of the maintenance works, which points out interrelationships between the knowledge creation process, its context and its associated knowledge assets, contributes not only explanations, insights and specific conclusions about the knowledge creation process and its management, but also ideas for extending conceptual developments and insights into the theoretical framework.

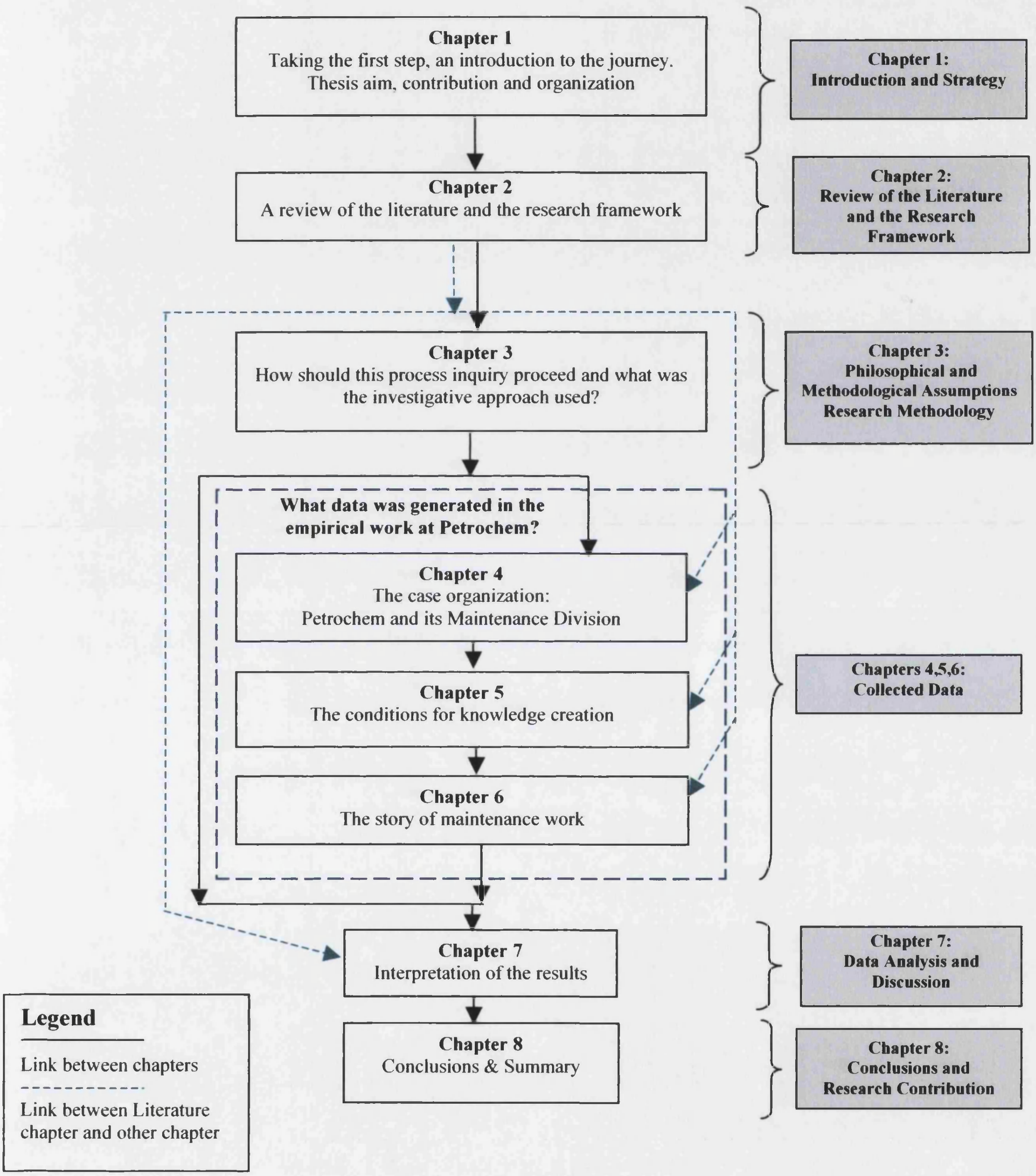
The interpretation commences with a group of themes that focus on the conditions that vitalize, energize and give quality to the knowledge creation process and to its context and bind participants in it. Then, the chapter proceeds with an analysis of the four stages of the SECI process as these are identified in the natural flow of maintenance works. Hence, initially the skill acquisition process and the situations that allow personnel to gather contextual and other information are analyzed through the prism of the socialization process that enables the transfer and accumulation of tacit knowledge and the collection of internal and external information. Analysis then shifts to the fault identification process as the externalization stage of knowledge creation in which maintenance personnel explicate their tacit knowledge for equipment repairs. The planning and scheduling function of the maintenance organization corresponds to the combination stage of knowledge creation, since it involves the acquisition, integration and processing of explicit knowledge for the synthesis and the dissemination of complex knowledge sets. The execution of maintenance works is seen as the final stage of the knowledge creation process in which personnel create and acquire new knowledge on technical issues and on the management and organization of maintenance works, that is on the organizational capacity for action. Concurrently to the analysis of the stages of the SECI process emphasis is given to the influence of the process context, and to the knowledge assets involved. The analysis of the knowledge creation process indicates its context-specific nature and points out the coexistence of different modes of this process. Their differences often depend on how and who participates in the process and reflect that the context of the knowledge creation process acts simultaneously as a platform for the sharing, integration, and utilization knowledge.

Chapter eight concludes with an overview of the thesis and a detailed presentation of the research contribution. The chapter along with the core contribution that has to do with the provision of a process view of knowledge creation argues that the research has also a multilevel theoretical, practical and methodological contribution. It explains the limitations of the research and the applicability of the findings to other organizational contexts. In conclusion, it considers some future research directions.

1.5 Summary

Chapter One has attempted to provide an introduction to the research journey that follows. First, it presented the general background, the initial motivation and the significance of the research. Then, it explained the thesis aim and the investigative focus, which endeavours to make sense of knowledge creation as a social process in a holistic manner. This objective was linked to two research questions: (i) How knowledge creation processes interrelate with their social and organizational context and their content, and (ii) how these interrelationships are influenced by individual and group actions and interactions. Moreover, the chapter pointed out that the research has a theoretical, a practical and a methodological contribution. It also presented an overview of this investigation.

Figure 1.2 **Thesis Organization**



2

A Research Framework and Associated Literature

2.1 Introduction

The purpose of this chapter is dual, since it not only aims at presenting the research framework for the pursuit of the research objective, but also at reviewing and critiquing relevant literature from the fields of organizational studies, knowledge management and knowledge processes in an attempt to map debates, issues and research gaps associated with the research framework in particular, and more broadly with processes of knowledge creation. This is pursued by a number of themes.

The first theme starts with the adopted definition of knowledge and a discussion on alternative perspectives and typologies on knowledge. Furthermore, this commencing theme explains that knowledge processes can be viewed from either a structural or processual perspective (Newell et al. 2002). Hence, the second theme deals with frameworks that address processes of knowledge creation and adopt a structuralist perspective (Spender 1996a, 1998; Blackler 1995; Nonaka 1994). More specifically, we depict and describe Nonaka's framework for its suitability to provide a view of knowledge creation as a social process in comparison to the other frameworks. A third theme explains the emergence of the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a), which constitutes the most recent and integrated version of Nonaka's framework (Nonaka 1991; 1994; Nonaka and Takeuchi 1995) and interrelates the development of the knowledge creation process with its context and its content. Thus, having explained that this framework involves the elements of the knowledge creation process that concern the research objective, the fourth theme presents how knowledge creation unfolds through a series of knowledge conversions, namely the SECI process. The fifth theme, which deals with the context for knowledge creation, presents the taxonomy of Ba that is used in this research. Maintaining the focus of attention on the context for knowledge creation, a sixth theme explicates the interest of this thesis on the social context and on the contribution of individual and group roles for its shaping, and introduces the knowledge activism framework (Von Krogh et al. 1997) that is also used in this investigation. Theme seven points out briefly the contribution of media and in particular of the role of information and communication technologies in shaping the context for knowledge creation. Besides the importance of the knowledge activist roles for the investigation of the knowledge creation context, my thesis is also concerned with a number of organizational conditions that influence social interactions and contribute to the building and energizing of the process context. These conditions, namely: autonomy, creative chaos, information redundancy, requisite variety and care, trust and commitment, are presented as an eighth theme.

Then, the investigation approaches the issue of the knowledge creation process content through the concept of knowledge assets (Nonaka et al. 2001a). Thus, the ninth theme presents a taxonomy for knowledge assets and explicates how these are of interest to the present research. The tenth theme explains that the thesis is also concerned with the way in which participants in the knowledge creation processes of the case organization develop and manage, both consciously and unconsciously, these knowledge assets.

Theme eleven addresses the issue of an appropriate management style for the process of knowledge creation and the issue of a suitable infrastructure for the support of this social process. The last theme, theme twelve, deals with the role of the knowledge vision within the knowledge creation process. The chapter concludes with a brief summary.

2.2 A definition of knowledge and a review of alternative perspectives on knowledge

A widely accepted definition of knowledge that is rooted in Plato's philosophical system (Plato 1993a; 1993b), and is also adopted by this thesis, views knowledge as a "*justified true belief*" (Polanyi 1962: 4). However, this definition has attracted various criticisms in relation to the alleged qualities of knowledge, particularly in terms of the justification, the truthfulness and the issue of belief (Machlup 1980; Dretske 1981; Gettier 2000; Bernecker and Dretske 2000). Some contemporary philosophers argue that Plato defines knowledge as "perception (αντίληψη - antilepse)" (Russell 1961). This perspective does not explain the nature of knowledge, but rather focuses on the process through which it is acquired, since the translation of the word "perception", which means "instead of reception" (Mandala 1993) in the Greek language, highlights the esoteric ability of an individual to understand.

Besides the knowledge definition debate, a review of the literature reveals that knowledge is dealt with in each of the social sciences. For example, frequently cognitive psychology makes a distinction between the knowledge of facts, namely declarative knowledge (knowing what), and procedural knowledge (knowing how), which is action-based knowledge (Anderson 1976; 1990; 1995). Economic perspectives on knowledge (Boisot 1995) focus on codification, abstraction and diffusion as dimensions of knowledge, and accept the existence of negative notions of knowledge, such as unwanted knowledge (Machlup 1980).

A great part of the literature concerning knowledge processes is influenced by the identification of the tacit dimension of knowledge (Polanyi 1946; 1962; 1966), on which Nonaka (1991; 1994) built a tacit/explicit knowledge epistemology. Polanyi (1966: 4) argues that tacit knowledge resides on a cognitive level within individuals, is relatively incommunicable and relates to Ryle's (1949) "know-how". On the other hand, explicit knowledge is defined as codified knowledge "transmittable in formal and systematic language" (Nonaka 1994: 16).

Both the tacit/explicit knowledge distinction and Polanyi's definition of knowledge have been questioned for their ability to "translate well to the organizational unit of analysis" (Robertson 1999: 23), which is also the unit of analysis of the present research. Such an argument is amplified by a common misinterpretation in management studies (Tsoukas 2003; Styhre 2004), which views tacit knowledge as knowledge-not-yet-articulated (Nonaka and Takeuchi 1995) and as knowledge relatively incommunicable (Boisot 1995; Nahapiet and Ghosal 1998; Scharmer 2000). However, it neglects the point that tacit knowledge can be articulated through narratives, such as stories (Patriotta 2003; Tsoukas 1998; Orr 1990) and mentoring (Swap et al. 2001), while since tacit knowledge involves both cognitive (beliefs, mental models etc.) and technical elements (personal skills) (Nonaka 1994; Nonaka and Konno 1998) its creation is not as difficult as its integration with other already existing types of knowledge (Leidner 1998).

Furthermore, and besides the distinction between tacit and explicit knowledge, the distinction of knowledge between the individual and the social or collective levels appears to be important in the literature that deals with knowledge processes (Nonaka 1991; 1994; Nonaka and Takeuchi 1995; Blackler 1993; 1995; Spender 1996a; 1996b; Walsh 1995; Lam 2000), since it triggers the debate about the nature of organizational knowledge, and whether individuals and organizations are both entities that learn (Huber 1991; Spender 1996b; Baumard 1999; Tsoukas and Vladimirou 2001).

The above-mentioned knowledge taxonomies and their incorporated assumptions, which amongst others accept the contextual, situational, pluralistic, mediated and contested character of knowledge (Błackler 1993), reveal that knowledge may be viewed from several perspectives. Hence, according to Alavi and Leidner (2001) knowledge can be viewed as a state of mind[2], as an object[3], as a process[4], as a condition of having access to information[5], or as a capability[6]. Furthermore, another more systematic clustering of knowledge perspectives (Venzin et al. 1998) recognizes the importance of the knowledge location[7], of the knowledge development process[8], and of the object of this development[9].

However, when the review of the literature comes to knowledge creation processes and the associated frameworks, the adoption of a distinction between a structural and a process perspective on knowledge (Newell et al. 2002) appears suitable for the delineation of their differences. Thus, the structural perspective, which is similar to the formistic knowledge paradigm (Tsoukas 1994) and to a functionalist perspective (Burrell and Morgan 1979; Schultze 1998; Venters 2002), perceives knowledge as a discrete, objective, static, largely cognitive entity and adopts the tacit/explicit distinction of knowledge (Newell et al. 2002). Despite criticisms, the structuralist perspective is useful when seeking to understand how and under what conditions different kinds of knowledge are involved, created and applied in knowledge creation (Robertson 1999), appropriate for the investigative focus of my research. The fundamental assumptions of this perspective underlie Nonaka's work (Nonaka 1991; 1994; Nonaka and Takeuchi 1995), which is based on Polanyi's assertion: "Once [knowledge] is discovered, it is held to be true" (Polanyi's 1966: 6) and accepts that individuals through the justification of personal beliefs in given contexts create and possess objective, time- and space-specific knowledge of the world.

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2 Accepts that individual knowing occurs through the development of understanding gained through experience or study.

3 Focuses mainly on knowledge manipulation and storage (Penrose 1959; Nelson and Winter 1977; Winter 1988).

4 Deals with the application of expertise and it can focus both on knowing and acting.

5 Organizational knowledge must be organized to facilitate access to and retrieval of content (Machlup 1980)

6 Suggests concentration on building core competencies, understanding the strategic advantage of know-how, and creating intellectual capital (Prahalad and Hamel 1990; Stalk et al. 1992; Teece 2000).

7 Emphasizes the result of the knowledge development process. Embodied (Zuboff 1988; Blackler 1995; Nonaka and Takeuchi 1995; Collins 1993) and encoded (Zuboff 1988; Blackler 1995; Collins 1993) knowledge belongs to this category.

8 Focuses on knowledge flows and on knowledge creation, sharing, and distribution processes. Encultured, embedded (Brown and Duguid 1991; Badaracco 1991; Collins 1993) and embrained (Blackler 1995; Collins 1993) knowledge belongs to this category.

9 Emphasizes where knowledge can be found, how it develops and how it is mediated. Procedural (Zander and Kogut 1995; Bohn 1994; Ryle 1949) and event knowledge belong to this category.

In contrast to Nonaka's viewpoint, other authors argue that knowledge is dynamic since it cannot be abstracted from its discovery and application (Spender 1996a). This approach shifts the focus of knowledge from the quality of truth to the context of its application and recognizes that the process of knowing is as important as knowledge itself, something that is acknowledged, amongst others, by Polanyi (1962; 1966) with the introduction of the term tacit knowing[10], which overcomes the "conceptual flexibility" of the term tacit knowledge (Whitley 2000). Hence, such a perspective that focuses on the process (Newell et al. 2002) follows an "epistemology of practice" in contrast to the structuralist perspective[11], which follows an "epistemology of possess" (Cook and Brown 1999: 381). Figure 2.1 summarizes the characteristics of the structural and the processual perspectives on knowledge.

Figure 2.1 **Structural vs. Processual Perspective on Knowledge**

Structural Perspective	Processual Perspective
Knowledge is a discrete cognitive entity possessed by people and organizations	Knowledge is rooted in practice, action and social relationships
Knowledge is objective and static	Knowledge is dynamic – the process of knowing is as important as knowledge
Knowledge exists at the individual and the collective level	Knowledge exists through the interplay between the individual and the collective level
Different types of knowledge dominate particular types of organizations	Organizations will be characterized by different types of knowledge and practices of knowing
Knowledge is created via specific social processes	Knowing occurs via social processes

Adapted from Newell et al. (2002: 8)

2.3 A framework for understanding processes of knowledge creation

Since the early 1990s a number of frameworks have been developed that adopt mainly a structuralist perspective on knowledge (Newell et al. 2002). Thus, Nonaka, Spender and Blackler have all developed frameworks, which attempt to (Robertson 1999): (i) explain the knowledge creation process and the way in which knowledge is used within an organization (Nonaka 1994; Spender 1996a, 1998), and (ii) map shifts over time in organizing and dominant forms of organizational knowledge at the macro level (Blackler 1995). This chapter does not attempt a detailed review of the fundamental assumptions and other principles of Spender's

10 Tacit knowing is "the active shaping of experience performed in the pursuit of knowledge" (Polanyi 1966: 6).

11 This perspective has also similarities with the knowledge category models, which categorize knowledge into discrete elements, and with intellectual capital models, which point out the importance of knowledge as an asset, according to the three-fold classification of knowledge management models proposed by McAdam and McCreedy (1999a; 1999b). Intellectual capital and knowledge categorization models (McAdam and McCreedy 1999a; 1999b) broadly fit within the functionalist perspective on knowledge (Schultze 1998), which accepts that knowledge is objective.

(1996a, 1998) and Blackler's (1995) frameworks, but chooses rather to focus attention on Nonaka's framework[12], due to its central role as the primary theory that guides both data collection and interpretation within the present investigation. However, this section deals, amongst other things, with the reasons that favoured the selection of Nonaka's framework in contrast to the other two.

Despite criticisms about its limited practical value (Garvin 1993; Boisot 1998), Nonaka's framework can be seen as a collection of managerial heuristics, which give some practical value to it, based on a philosophical background provided by Polanyi and aim at describing knowledge creation processes. An early version of the framework appeared in the early 1990s (Nonaka 1991) and integrated together, and for the first time, elements of the author's previous work (Nonaka 1988a; 1988b; 1990; Nonaka and Yamanouchi 1989; Nonaka and Johansson 1985) on knowledge creation. A more mature version of the framework appeared in mid-1990s (Nonaka 1994; Nonaka et al. 1994; Nonaka and Takeuchi 1995) that gave it a more concrete theoretical hypostasis by providing an organized system of principles. However, the framework evolved again in order to facilitate the need for describing aspects of the structure that support the process of knowledge creation. Thus, in 1998 Nonaka, building on the work of Nishida (1921; 1970) and Shimizu (1995), adopted the concept of Ba (Nonaka and Konno 1998), which is the context for knowledge creation. More recently, the framework incorporated the concept of knowledge assets from the market perspective on knowledge (Grover and Davenport 2001), which views knowledge as an asset (Boisot 1995; 1998) and defined them as the inputs, outputs and moderators in knowledge creation processes (Nonaka et al. 2000b; Nonaka et al. 2001a).

While Nonaka's framework on knowledge creation adopts Polanyi's (1962) definition of knowledge, it also adopts the tacit/explicit epistemology of knowledge from, e.g. Li and Gao (2003), and a constructionist perspective on the nature of reality (Berger and Luckmann 1966; Gergen 1999). Individuals acting in an organizational context (Robertson et al. 2003) are the primary sources of knowledge creation (Nonaka 1994; Nonaka and Toyama 2002). The framework assumes that social knowledge does exist, and that it is created in the same way as individual knowledge (Robertson 1999) and crystallized as part of the organizational knowledge network (Hansen 2002). Thus, organizational knowledge creation involves the development of a new content or the replacement of the existing content within the organization's tacit and explicit knowledge through social and collaborative processes as well as through an individual's

[12] Reference to Nonaka and his framework throughout the present thesis concerns the Dynamic Theory of Organizational Knowledge Creation as this is described in a number of articles and books (Nonaka 1991; 1994; Nonaka et al. 1994; Nonaka and Takeuchi 1995) and its most recent extensions that form the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a).

cognitive processes (Alavi and Leidner 2001). However, organizational knowledge that has the same meaning to everyone cannot exist, since an individual's cognition provides interpretations different from another's (Robertson 1999).

In contrast to Nonaka, Spender (1998) highlights an important distinction between individual and social knowledge, while he acknowledges that the existent forms of social knowledge are created and understood by individuals within the organization and interact dialectically with individual types of knowledge to create new knowledge at both the individual and the organizational level[13] (Newell et al. 2002).

Following others who criticized organization theory for just "observing" knowledge creation processes (Ekstedt et al. 1999), Nonaka rejects the information-processing paradigm. Thus, in contrast to organization theory, Nonaka's framework views organizational knowledge creation as a continual conversion between the tacit and explicit dimensions of knowledge and as a growing spiral flow, as knowledge moves from the individual towards the group and the organizational levels. This assumption, which underlies the existence of a reciprocal hierarchy amongst data, information and knowledge according to which knowledge builds on information that is extracted from data (Liebenau and Backhouse 1990; Boisot 1998) and vice versa (Tuomi 1999), views information from a semantic perspective (Shannon and Weaver 1949; Nonaka 1994, Nonaka et al. 1994, Nonaka et al 2001a)[14]. Hence, according to this perspective, as information communicates/flows individuals interpret it and assign meanings, according to their beliefs and this identifies knowledge. However, the differences between knowledge and information are not limited only to the fact that the first is about beliefs and meaning (Dretske 1981), but also to the fact that it is validated and justified through its application in action within a specific context (Machlup 1980). Moreover, knowledge is also situated and relational (Nonaka and Takeuchi 1995; Hayek 1945; 1989; Robertson et al. 2003) and dynamic (Lanzara and Patriotta 2001), as it is created in social interactions among individuals and organizations (Nonaka 1994; Nahapiet and Ghoshal 1998; Chua 2002).

The ontological dimension of the knowledge creation process suggests that individual knowledge that is created moves through the group and the organizational levels with the

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[13] Spender (1996a) argues that data and meaning are two different kinds of organizational knowledge, which coupled with a definition of tacit knowledge as knowledge not yet been abstracted from practice, identify four different types of organizational knowledge (Spender 1994): (i) individual/explicit (conscious), (ii) individual/implicit (automatic), (iii) social/explicit (objectified), (iv) social/implicit (collective).

[14] Galliers & Newell (2003), after Checkland, see information as being derived from data by individuals applying their existing knowledge.

contribution of "communities of interaction", which develop it and amplify it, both formally and informally (Nonaka 1994). The ontological dimension, along with the tacit/explicit knowledge distinction, which is considered as the epistemological dimension of Nonaka's framework, form an "epistemologically-based knowledge spiral model" (Lessem 1998) that identifies four different patterns of interaction between tacit and explicit knowledge.

Nonaka identifies four knowledge creation modes, namely socialization, externalization, internalization, and combination, which correspond to the four different patterns of interaction between tacit and explicit knowledge. The four knowledge creation modes are interdependent and intertwined. The socialization mode refers to the conversion of tacit knowledge to new tacit knowledge through social interactions and shared experiences among individuals. Externalization refers to the conversion of tacit knowledge into new explicit knowledge through the expression and translation of tacit knowledge into forms so that others can understand it. The combination mode, which is similar to information processing, refers to the process of converging explicit knowledge into more complex and systematic explicit knowledge by merging, categorizing, reclassifying, and synthesizing existing explicit knowledge. Finally, internalization is the process of embodying explicit knowledge into tacit knowledge and has some similarities with the notions of training and learning-by-doing. Organizational knowledge creation, as distinct from individual knowledge creation, takes place when all four modes of knowledge creation, which are also called the SECI process, are organizationally managed to form a continual cycle.

The organizational knowledge-creation process ideally involves five main steps, which incorporate the time dimension into the theory. These phases are: (i) the sharing of tacit knowledge, (ii) the creation of concepts, (iii) the justification of concepts, (iv) the building of an archetype, and (v) the distribution or the "cross-levelling" of knowledge (Nonaka and Takeuchi 1995; Von Krogh et al. 2000a).

The organizational knowledge creation process starts with relating the theoretical constructs and models created by individuals to a corporate organizational setting (Nonaka 1994). In this setting individual knowledge is enlarged, amplified and justified. "Hands-on" experience is the most significant way for the accumulation of individual tacit knowledge (Nonaka 1994). The quality of that tacit knowledge is influenced by two important factors, the variety of an individual's experience, which is a necessary but not sufficient factor to raise the quality of tacit knowledge, and "knowledge of experience", the essence of which is the embodiment of knowledge through a deep personal commitment into bodily experience (Nonaka 1994). However, these factors are counterbalanced by a further approach to knowledge creation that raises the quality of explicit knowledge and is called knowledge of rationality. Individual knowledge is enlarged through this interaction between experience and rationality, and crystallized into a unique perspective, based on individual belief and value systems and with a process similar to what Schoen (1983) calls "reflection-in-action". This knowledge becomes a source of varied interpretations of shared experience with others (Nonaka 1994).

The articulation and amplification of an individuals' knowledge through social interaction and mainly face-to-face dialogues signifies the initiation of the knowledge creation process (Bjorkeng et al. 2004). This step is critical since the sharing of tacit knowledge in the form of feelings, emotions, insights and mental models requires mutual trust (Nonaka 1994). In addition, individuals can also perform demonstrations that enhance personal skills. During this stage, in which knowledge conversion is dominated by externalization, knowledge creation can be facilitated by the construction of a "field" or a self-organizing team, which could accommodate imaginative thinking and add flexibility (Nonaka and Takeuchi 1995). Such teams also build mutual trust among members and help the conceptualization of the shared implicit perspective through continuous dialogue among members. Then, based on an organization's ability to share tacit knowledge, a concept is created. The concept may be a new product, a manufacturing process description, or as in the maintenance organization of the present research the specifications for a repair. Initially the concept is in the form of a shared tacit mental model, which is verbalised into words and phrases, and at a later stage, crystallized into some concrete and explicit form. The central mode of knowledge conversion during crystallization is internalization, since the individuals test the reality and applicability of the concept. The concept creation and crystallization process is a dynamic and social process, which is facilitated by the existence of redundant information, occurs at a collective level (Nonaka 1994) and reflects the negotiated nature of knowledge through dialogues.

The third stage of the knowledge creation process requires the justification of the newly created concept by determining whether it is "truly" worthwhile for the organization (Nonaka and Takeuchi 1995). Justification determines the "quality" of the created knowledge and involves criteria or "standards", which could be abstract and not necessarily objective and factual, for judging truthfulness (Nonaka and Takeuchi 1995; Giroux and Taylor 2002).

In the fourth phase, the justified concept is converted into an archetype, which is something tangible or concrete, and it is built by combining newly created explicit knowledge with existing explicit knowledge. This phase is similar to the combination process. However, the building of archetypes is a complex process, requiring the dynamic cooperation of various groups and individuals, and attention to detail. Finally, once the archetype is built, it moves to a different ontological level, meaning that knowledge is spread both intra-organizationally and inter-organizationally.

The cross-levelling of knowledge can trigger a new cycle of knowledge creation. During this phase, the created concept is integrated into the organizational knowledge base, which comprises a whole network of organizational knowledge. Autonomous individuals can also facilitate the transferring of created knowledge elsewhere and apply it across different levels and boundaries (Nonaka 1994).

At this point, it should be pointed out the fact that neither Spender's framework (1996b), as the author himself admits, nor Blackler's[15] (Blackler 1995; Blackler et al. 1998), can explain how various types of knowledge interact and thus how an organization favours knowledge creation and application processes, similarly to Nonaka's framework. Therefore, they do not facilitate the investigative focus of this thesis, which does seek to explain such processes. The rather limited practical use of Blackler's (1995) framework lies in the fact that it could associate the public and bureaucratic (Weber 1947) case organization, with dominant types of knowledge and, in doing so, it could increase - and only indirectly - understanding of the ways this knowledge could be managed. Hence, according to this framework, Petrochem (a typical technology intensive organization with hierarchical division of labour and control) puts emphasis on knowledge embedded in technologies, rules and procedures, while its maintenance division focuses on the embodiment of competencies by its key members. For Blackler (1995), the case organization is a combination of a knowledge-routinized and an expert-dependent organization. However, both Blackler's and Spender's frameworks cannot be used as analytical tools for the delineation of the development of the knowledge creation process and its interrelation with its context and its content, and this favours Nonaka's framework for the investigation of such processes.

2.4 The unified model of dynamic knowledge creation

The Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a) constitutes the most recent and integrated version of Nonaka's framework on knowledge creation. This model explains that organizational knowledge is created through social processes of knowledge

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[15] Blackler (1995), extending Collin (1993), suggested that different types of knowledge exist at either the individual or the collective level. His framework suggests an approach that instead of regarding knowledge as something people have, argues that knowing is something that people do.

conversions[16] between tacit and explicit knowledge and incorporates all the fundamental assumptions of the dynamic theory of knowledge creation (Nonaka 1994). It also addresses the issues of the process context and the content, with the concept of Ba (Nonaka and Konno 1998), and the concept of knowledge assets (Nonaka et al. 2000b; Nonaka et al. 2001a), in a similar way to Walsham (1993), who addresses the issues of the context and the content in organizational change processes, and to Thompson and Walsham (2004), who address the issue of context in knowledge processes.

According to the Unified Model of Dynamic Knowledge Creation new knowledge is created with the interrelation and the emerging or deliberate management of its three constituent elements (Nonaka et al 2001a; 2001b; 2000): the SECI process, Ba (which provides the shared context for knowledge creation), and knowledge assets (which are the inputs, outputs and moderators of the knowledge-creating process). Nonaka's Model occupies a central role in the present thesis not only as a guide for the collection of data, but also as the conceptual lens for their interpretation, due to its in-depth reference to the elements of my investigative focus. Therefore, in order to identify issues and debates, and to delineate their role in my thesis, the next section will examine in greater detail the frameworks' three constituent elements, focusing also on their management and on the role of individuals within knowledge creation processes.

2.5 The SECI process

2.5.1 Socialization

The commencement of the knowledge creation process is signified by the socialization stage of knowledge conversion, which requires the sharing of experiences and thereby the creation of tacit knowledge, in the form of technical skills or knowledge structures that enable the formation of accurate explanations, the coordination of actions and the adaptation of behaviour (Cannon-Bowers et al. 1993) - shared mental models in other words. Despite the relative difficulties in its formalization due to its situated nature, the acquisition of tacit knowledge is achieved when people project themselves into the reality and thinking process of another individual. Thus, the building of such shared experience requires spending time together or living in the same environment (Nonaka and Takeuchi 1995). Moreover, socialization not only brings new employees into an organization's culture, but also continues throughout their career (Ivancevich and Matteson 1999).

[16] Adopted from Anderson's (1983) work in cognitive psychology

The present investigation examines the socialization stage of knowledge creation process within the maintenance case organization by looking at aspects of its traditional apprenticeship, where apprentices learn the tacit knowledge needed in their craft through observation, imitation and practice (Nonaka et al 1998b), as in the case of Matsushita (Nonaka and Takeuchi 1995). Hence, in the case organization, employees acquire maintenance skills. Moreover, the investigation is interested in informal social meetings both inside and outside the workplace, as in the case of Honda's "brainstorming camps" (Nonaka and Takeuchi 1995), where tacit knowledge such as worldviews, mental models and mutual trust can be created and shared. Furthermore, the investigation seeks examples of socialization that extend beyond organizational boundaries and demonstrate the exchange and transfer of tacit knowledge embedded in customers or suppliers (Van de Ven 1976; Nonaka et al. 2001b; Grant and Baden-Fuller 2000), since such intra-firm interactions often comprise an exploitation and symbiosis element that allows coevolutionary knowledge creation (Nishiguchi 2001). All these examples of socialization, which concern the transferring and the accumulation of tacit knowledge and the collection of intra- and extra- firm social information (Nonaka et al. 1994; Nonaka et al. 2001b), facilitate the pattern-matching mode of analysis of collected data (see Chapter Three).

Additional theoretical support to this investigation of socialization that achieves a minor degree of theoretical triangulation (Denzin 1978) is also attempted with the use of a model that describes this social process within organizations. Despite the existence of various models describing socialization in organizations (Wanous et al. 1984), there is a general consensus that these can be included in Feldman's (1976; 1981) three-stage model. Hence, according to this model, the first socialization stage, anticipatory socialization, involves all those activities the individual undertakes or undergoes prior to entering an organization, such as recruitment programmes. The second stage, accommodation socialization, starts with an individual entering into an organization, when (s)he establishes new interpersonal relationships with both co-workers and supervisors, learns the tasks to be performed, clarifies their role in the organization, participates in various formal and informal groups, and initiates self-reflection on the demands of the job and role (Ivancevich and Matteson 1999). Effective accommodation socialization can be enhanced with the communication of a vision, training, performance evaluation, and the assignment of demanding supervisors and challenging tasks, which often achieve team conformity (Ivancevich and Matteson 1999). The third stage, which is called role management and moves further than the requirements of an individual to adjust to demands and expectations of the immediate work group, introduces the employee to a broader set of issues and problems, promoting requisite variety (Ashby 1957), and can be achieved with mentoring and role modelling (Ivancevich and Matteson 1999). Thus, this thesis uses, in addition, Feldman's (1976;

1981) model for assisting the delineation of the socialization stage of knowledge creation within the maintenance case organization.

2.5.2 Externalization

The second stage of knowledge creation, namely externalization, is the process of articulating tacit knowledge into explicit concepts. Explicated tacit knowledge, which often takes the form of metaphors (Kendall and Kendall 1993), analogies, concepts, hypotheses, or models, crystallizes and can be shared by others, and becomes the basis of new knowledge. This is so because it creates new, explicit concepts (Nonaka and Takeuchi 1995). For this process, networking among individuals and dispersed communities is more important than relying on IT networks (Swan et al. 1999).

Externalization, which is typically seen in concept creation, is triggered by dialogue and collective reflection. Hence, conversation management is an important knowledge enabler, since not only does it influence the sharing of tacit knowledge during externalization, but also every phase of the knowledge creation process (Von Krogh and Roos 1995; Von Krogh et al 2000a). Dialogue and reflection allow the successful conversion of tacit knowledge into explicit knowledge by setting in operation a metaphor/analogy communication mechanism (Bateson 1979; Nonaka 1994), which recognizes contradictions through the use of metaphor (Hirschheim and Newman 1991) and resolves them through analogy. Metaphor is a way of perceiving or intuitively understanding one thing by imaging another thing symbolically and creates novel interpretations of experience (Donellon et al. 1986). Analogy allows the functional operation of new concepts or systems to be explored by reference to things that are already understood (Nonaka 1994).

Live metaphors (Tsoukas 1991), such as Honda's "man-maximum, machine-minimum" (Nonaka and Takeuchi 1995), are helpful in conceptual development and in particular during new product development, in combination with structured methods and information and communication technologies (ICT) (Scarbrough and Corbett 1992; Ciborra and Patriotta 1996; Doyle 1999). However, examples of new product development do not link externalization to broader knowledge creation processes, while only few academics (Lessem and Palsule 1999) realize the interrelation of externalization with knowledge creation and encourage further investigation.

The professional maintenance organization in the present research is a knowledge intensive firm involved in creative problem framing and solving activities[17] (Newell at al. 2002; Gray and Chan 2000; Dougherty 2004; Kim and King 2004). This organization converts tacit knowledge into explicit knowledge for the creation of concepts about maintenance repairs that consist of knowledge about the identified equipment fault, and the required repair techniques, tools, spare parts etc. The development process of these maintenance repair concepts is another concern of this thesis.

Moreover, quality control circles are also externalization examples that concern the present investigation, since they allow employees to improve their skills or processes by articulating the tacit knowledge accumulated on the shop floor, often in the form of feedback after the completion of a maintenance task (Nonaka and Takeuchi 1995; Kess and Haapasalo 2002).

2.5.3 Combination

Combination is the process of converting explicit knowledge, such as developed concepts, into more complex and systematic sets of explicit knowledge or the process of systemizing concepts into a knowledge system (Nonaka 1991). This stage of knowledge conversion involves the acquisition of explicit knowledge and then, according to the case, its further processing into new explicit knowledge, its synthesis and integration to already existing explicit knowledge and its dissemination (Nonaka et al. 1994). Explicit knowledge is collected from both inside and outside the organization through media, such as documents, meetings, telephone conversations or computerized communication networks, and then it is combined, edited or processed to form new knowledge. Reconfiguration of existing information through sorting, adding, combining, and categorizing of explicit knowledge can also lead to new explicit knowledge (Nonaka and Takeuchi 1995). The new explicit knowledge is then disseminated among the members of the organization. The use of computerized communication networks and large-scale databases can facilitate the various steps of combination (Nonaka et al. 1998a; Nonaka et al. 1998b; Nonaka et al. 2000c; Nobeoka and Baba 2001).

The present thesis examines combination through the process for the creation of maintenance job plans and reports, which require the collection of information from various sources and its synthesis. Furthermore, another characteristic aspect of combination within the case

[17] Problem solving refers to the application of technical and scientific knowledge. Problem setting requires the figuring out of the relevant 'things' of the situation and defining 'the decisions to be made, the ends to be achieved, and the means which may be chosen' (Schoen, 1983: 40).

organization concerns the creation of systemic, explicit knowledge through the "breakdown of concepts" (Nonaka et al. 1994). In my case the concept breakdown process does not involve the breakdown of a corporate vision into product concepts (Nonaka and Takeuchi 1995), but concerns the breakdown of the created maintenance repair concept for the synthesis of a more complex and detailed maintenance repair schedule.

Besides the consideration of the combination process as an integral part of the unified model of dynamic knowledge creation, a similar process is also important for the creation of new intellectual capital (Nahapiet and Ghoshal 1998). However, the intellectual capital perspective accepts that the combination process is much broader than Nonaka's combination of explicit knowledge, since the combination of social capital develops both tacit and explicit social knowledge. Moreover, this perspective explains that prerequisites for the combination process that creates new intellectual capital are the existence of the opportunity for combination, the expectancy of the involved parties that the combination process will create value, their motivation to proceed with this process, and of course their combination capability.

2.5.4 Internalization

The embodiment of explicit knowledge into tacit knowledge, namely internalization, is the fourth stage of the SECI process. Through internalization, the created explicit knowledge is shared throughout an organization and converted into tacit knowledge by individuals in the form of shared mental models or technical know-how (Nonaka et al. 2001a). The accumulation of tacit knowledge at the individual level can then set off a new spiral of knowledge creation, when it is shared with others through socialization. Internalization is also closely related to "learning by doing" (Nonaka et al. 2001a; Akbar 2003), despite criticisms that this assumes an unproblematic process of absorbing the existing knowledge and neglects the nature of the learner, of the world, and of their relations unexplored (Lave and Wegner 1991; Newell 1999). However, this requires the fostering of a climate for simulation and experimentation that tolerates possible failures (Leonard 1998).

The present thesis attempts to explain internalization by providing examples of increasing personal expertise through action and practice, through the acquisition of real world knowledge (Nonaka et al. 1994) in other words. The actualization of maintenance repairs through action and practice allow this internalization of explicit knowledge (Nonaka 1994; Nonaka and Takeuchi 1995), since thereby employees enrich their tacit knowledge base.

Moreover, experimentation and simulation, the acquisition of virtual world knowledge (Nonaka et al. 1994; Nonaka and Takeuchi 1995), as examples of internalization are another concern of this thesis. Naturally occurring or forced experimentation in maintenance repairs could facilitate reflection and help trainees to understand both the organization and, themselves, while it creates requisite variety (Ashby 1957) and triggers innovation (Leonard 1998). This could be achieved through grand or modest experiments, which often have an improvisational character (Leonard 1998) or even through training programmes. New technologies, such as computer simulations, benefit experimentation, since they allow the realization of the trial-error cycle with reduced costs (Thomke 2001).

Appendix One, using an adaptation of Nonaka et al. (1994), illustrates in summary form the stages of the SECI process in the Maintenance Division.

2.6 Ba, the platform for knowledge creation: a definition and a taxonomy

The adoption by Nonaka's framework of the principle that knowledge is context-specific and that it cannot be understood apart from it being situated in cognition and action (Suchman 1987) contributed to one of the most recent extensions of this framework with the introduction of the concept of Ba (Nishida 1921; 1970; Shimizu 1995; Nonaka and Konno 1998). Ba offers the physical, virtual and/or mental context for the creation, sharing and exploitation of knowledge (Nonaka et al. 2001b).

One basic characteristic of Ba is the harbouring of meaning within a time/space nexus comprised of social, cultural and historical contexts that provide the basis for individuals to interpret information to become knowledge (Nonaka and Konno 1998: 41). While the present thesis recognizes the importance of such contexts within the case organization and provides in many instances rich information about them, it is primarily concerned with a second characteristic of Ba, which is the importance of interactions. Ba promotes the sharing, recreation, and amplification of an individual's knowledge through interactions with others or between individuals and their environments. These interactions shape the social context of the knowledge creation process. Moreover, a common language facilitates these interactions, commits participants in Ba through their actions and interactions and shapes their worldviews (Nonaka 1994; Naito 2001; Bechky 2003). The generation and regeneration of Ba provides the energy, quality and place for knowledge creation, but this is also a two-way process, since the knowledge creation process itself creates Ba, in this case, a boundary of new interaction and interpretation (Nonaka et al. 2001b). This view about the interrelated role of Ba with the knowledge creation process is in contrast to the literature, which sees knowledge as residing within the individual (Grant 1996), whereas the role of the organization is to apply this knowledge rather than to create new knowledge.

The concept of Ba has some fundamental differences with the concept of Information-Space (Boisot 1995), which despite its intention to explain knowledge creation and diffusion, belongs to the market approach on knowledge management (Grover and Davenport 2001). Thus, Boisot's framework views the Information-Space as a conceptual tool for the description of social learning process by means of which new knowledge and information can enter the system. In contrast, the concept of Ba enables the interpretation of information flows creating new organizational knowledge that resides within and between individuals. This process incorporates social learning.

Furthermore, the concept of Ba can sometimes be identified, despite opposing arguments (Nonaka et al. 2001a), with the concept of communities of practice[18] (Lave and Wegner 1991; Wegner 1998; Wegner et al. 2002; Brown and Duguid 1991) given the existence of a feeling of commitment, the importance of interactions (Wegner et al. 2002) and changes both at the individual and macro level, occasioned by with the building of competencies (Leonard-Barton 1992) and the creation of new knowledge (Breu and Hemingway 2002). However, a community of practice emphasizes on the learning of knowledge embedded in the community, while Ba is a place for knowledge creation. Furthermore, Ba has a "here and now" quality (Nonaka et al. 2001a) that actively relates individuals, in contrast to communities of practice, in which identity-giving memberships are formed by the task, culture and history and create discontinuities between participants and non-participants (Wegner 1998).

Figure 2.2 **Types of Ba within Knowledge Creation**

	Originating Ba	**Dialoguing Ba**	**Systemizing Ba**	**Exercising Ba**
Stage of Knowledge Creation	Socialization	Externalization	Combination	Internalization
Type of Interaction	Individual	Collective	Collective	Individual
Involved Media	Face-to-face	Face-to-face	Virtual	Virtual
Characteristics	- Interactions promote the sharing and the transferring of experiences, feelings,	- Mental models and skills are shared, articulated and converted into	Information technology offers a virtual collaborative environment for its	- Embodiment of explicit knowledge by continuous self-refinement and

[18] Members of a community of practice become informally bound by the value that they find in learning together, whilst they accumulate knowledge (Wegner et al. 2002: 7).

Figure 2.2 **Types of Ba within Knowledge Creation**

	Originating Ba	Dialoguing Ba	Systemizing Ba	Exercising Ba
	emotions and mental models, and the conversion of tacit knowledge - Individuals sympathize or empathize with others - Requires a knowledge vision and an enabling organizational culture	common terms, and then articulated as concepts through dialogues. - Triggers self-reflection - Synthesizes the transcendence and reflection through thought	creation.	active participation similarly to a community of practice (Lave and Wegner 1991) - Requires the sharing of time and space
Construction	Not always consciously	Consciously	Consciously	Not always consciously

Based on Nonaka and Konno (1998)

Figure 2.2 is an adaptation of a taxonomy proposed by Nonaka and Konno (1998) that identifies four types of Ba corresponding, by no means exclusively, to the four modes of knowledge creation. These types of Ba, which are: (i) Originating Ba, (ii) Interacting (Dialoguing) Ba, (iii) Cyber (Systemizing) Ba, and (iv) Exercising Ba, are defined by two dimensions. The first dimension is the type of interaction, that is, whether the interaction takes place individually or collectively. The second dimension is the media used in such interactions, that is, whether the interaction is through face-to-face contact or virtual media. While Figure 2.2 summarizes the basic characteristics of each type of Ba, this investigation focuses primarily on the interactions dimension of Ba by identifying key roles within the knowledge creation process of the case organization. This is explained in the following section.

The creation of organizational knowledge is facilitated by the conscious or unconscious building, maintenance and utilization of the four types of Ba (Reinmoeller and Chong 2002). Thus, for example, within our case organization, the building of a team through the selection of individuals of various trades and with the right mix of specific technical knowledge and capabilities is a case of consciously constructed dialoguing Ba that influences the formation and development of ideas about repairs (Sen 2004; McAdam 2004).

2.7 Ba and the importance of knowledge creating roles

Individual and collective interactions constitute one of the dimensions of Ba, and the present research aspires to explain how knowledge creation interrelates with its context, Ba in other words. Thus, the adoption of an appropriate framework, though which such interactions will be associated to the knowledge creation process, is of vital importance for the realization of the research objective. However, due to the nature and the complexity of both group and individual interactions, this thesis makes the assumption that there is value in attempting to understand these interactions through a framework that explicates roles, or characteristic actions and interactions[19], in knowledge processes. The need for the use of such a framework is amplified, since the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a), which occupies the central role by which collected data are interpreted, is of itself unable to explain how individuals generate tacit knowledge and how the obvious agency problems are resolved (Spender 1996a), such as the contribution of individuals to the utilization of tacit and explicit knowledge in social processes (Bennett 1998).

The role of individuals in knowledge processes is exemplified by middle managers who play critical roles in the management of organizational knowledge, especially during change management initiatives (Scarbrough and Burrell 1996). Thus, organizations often introduce positions, such as knowledge coordinator and knowledge manager (Ichijo et al.1998; Bukowitz and Williams 1999), Chief Knowledge Officer (Earl and Scott 1999), or knowledge strategist (Ruggles 1998), with duties related to the management of knowledge creation, storage, retrieval, and utilization. Amongst other things, these positions aim at dismantling organizational barriers, aligning individual motivation with corporate goals, discovering new opportunities (Kluge et al. 2001), and focusing on the impact of knowledge in shaping the organization and its strategic direction (Ruggles 1998).

However, the emphasis of Western approaches on processes of knowledge use and reuse is in contrast to the Japanese approach, which focuses on knowledge creation (Lam 1997; Cohen 1998). This has had an influence on frameworks dealing with roles within knowledge processes. Hence, a significant part of the literature focuses on roles dealing mainly with the administration of explicit types of knowledge (Bukowitz and Williams 1999). The roles of the knowledge editor, knowledge engineer, and knowledge broker, with responsibilities ranging from knowledge repository management to coaching, are oriented towards knowledge use and reuse (Ruggles 1998). Furthermore, Markus (2001) identifies three major roles in knowledge reuse processes. The knowledge producer either records explicit knowledge or makes tacit knowledge explicit. The knowledge intermediary is similar to, but broader than, the role of the knowledge coordinator (Bukowitz and Williams 1999). Knowledge intermediaries prepare knowledge for reuse and dissemination performing some functions similar to the combination mode of knowledge creation. The knowledge consumer or knowledge reuser retrieves the knowledge

[19] Definition of the term "role" according to The Concise Oxford Dictionary.

content and applies it in some way, like in the internalization stage of knowledge creation (Nonaka et al 2001a).

However, and despite the phenomenal correspondence between Markus' (2001) roles and Nonaka's SECI process, Markus' framework is not suitable for the exploration of individuals' interactions in knowledge creation processes, due to its rather limited focus on controlling processes of knowledge reuse. Furthermore, it silences the importance of moving across boundaries, exposure to a variety of new ideas and issues and accumulation of tacit knowledge. An appropriate framework, aligned to the needs of the present research, should recognize that individuals are the driving force in social processes of knowledge creation, since their knowledge, expertise and skills make them a valuable resource to an organization (Drucker 1993). Moreover, such a framework should be in position to address, not necessarily explicitly, issues that influence the quality of interactions and consequently the quality of Ba. For example, intention, autonomy and environmental fluctuations are three factors that energize interactions by ensuring and moderating individual and group commitment within an organizational setting (Nonaka 1991; 1994). Intention is concerned with how individuals form their approach to the world and try to make sense of their environment, while autonomous action within an organization increases the possibility of interactions to introduce unexpected opportunities. Moreover, environmental fluctuations or discontinuities can generate new patterns of interaction between individuals and their environment.

In contrast to those approaches that seek to control knowledge processes are perspectives that tend to recognize the individuals' role as the primary enablers of knowledge creation processes and focus, amongst others, on the issues of experience transfer and accumulation and on the shaping of an environment for the creation of tacit knowledge (Ichijo et al. 1998). Within this perspective Von Krogh has proposed the knowledge activism framework[20] (Von Krogh et al. 1997; Von Krogh et al. 2000a). This framework does not view individuals as knowledge producers, but considers them as the primary knowledge creation enablers and focuses on their roles as energizers and coordinators of knowledge creation efforts. According to this framework, these roles initiate, focus and reduce the time and cost needed for knowledge creation, and also leverage knowledge creation initiatives throughout the corporation. The suitability of Von Krogh's framework for the identification and description of knowledge enabling roles within the four different types of Ba lies also in its ability to address these roles

[20] Reference to Von Krogh and his framework throughout the present thesis concerns the knowledge activism framework as this is described in Von Krogh et al. (1997) and Von Krogh et al. (2000a).

not only at the individual level, but also at the group level. Therefore, it can describe both individual and collective interactions that formulate Ba.

Moreover, according to this framework, three interrelated roles enable knowledge creation: "the catalyst of knowledge creation", "the connector of knowledge creation initiatives" (knowledge connector), and "the merchant of foresight". The basic skills and other characteristics of these roles are summarised in Figure 2.3. The knowledge creation catalyst mainly creates Ba and triggers externalization, in a manner that can be likened to a chemical catalyst. The knowledge connector role is similar to the role of information broker (Brown and Duguid 2000). This role selects information provided by an informal (Wegner 1998; Buechel and Raub 2002) or a formal (Badaracco 1991) web of connections, and ensures the articulation and transfer of knowledge to the organization. The role of merchant of foresight provides direction to the knowledge creation process. Somewhat in contrast to Von Krogh et al. (1997), however, the present research views these three roles as independent and assumes that, within a knowledge creation processes, they can be performed either by the same or by a different individual or group. Von Krogh et al. (1997) are silent as to whether the three roles can be performed by different people.

Figure 2.3 Skills and Other Characteristics of the Three Knowledge Activist Roles

Knowledge Catalyst	Knowledge Connector	Merchant of Foresight
Motivational skills	Historic understanding of the company's development	Ambassador for the company's knowledge vision.
Interpersonal skills	Narrative skills: Detects, formulates, and tells stories of knowledge creation	- Skills in strategic tools and analysis. - Acts similarly to an entrepreneur chief knowledge officer (Earl and Scott 1999).
Intervention skills: Improves group relationships. Facilitates the sharing of tacit knowledge and concept creation	- Cartographical and visual skills: Uses, develops and maintains shared maps of cooperation[21] (Von Krogh and Roos 1992) and creates imagined communities (Von Krogh et al. 1997), facilitating the transferring of tacit knowledge - Partial equivalence to the role of a technologist chief knowledge officer (Earl and Scott 1999).	Broad understanding of the company's strategy process

[21] Dynamic tools that structuring discussion and engage in knowledge exchange

Figure 2.3 Skills and Other Characteristics of the Three Knowledge Activist Roles

Knowledge Catalyst	Knowledge Connector	Merchant of Foresight
- Analytical skills: Helps the group to develop a charter of their tasks and responsibilities by asking the why, how, what, where, when and who questions. - Equivalent to the role environmentalist chief knowledge officer (Earl and Scott 1999).	Analytical skills: Draws connections between knowledge-creation initiatives Connects "solution owners" and the "problem owners" (Von Krogh et al. 1997; March and Olsen 1976).	Has motivational skills, sells ideas and promotes the knowledge vision
Broad social network inside and outside the company allows moving across boundaries and exposing to experiences	Broad social network within and outside the company. Connects microcommunities[22] of knowledge.	Unconventional thinking and visionary skills facilitate concept justification in front of the company's knowledge vision.
Operational understanding of the business, key products and markets		
Creates spontaneous or deliberate forms of Ba where participants utilize and leverage personal experience		
Mixes tradition with creativity		
Acquires responsibility, will, intention and stamina to follow up long-term commitments, needs and wishes (Davenport and Beck 2001)		

Based on Von Krogh et al. (2000a)

2.8 Ba, media and the role of ICT in knowledge creation

The media that are used in Ba interactions, that is, whether the interactions are through face-to-face contact or through virtual media, such as books, memos or ICT, comprise the second dimension of Ba (Nonaka and Konno 1998). The present research recognises the existence of various genres of communication and media (Yates and Orlikowski 1992) as important elements of the knowledge creation process, since, for example, they facilitate the creation of actual, virtual of mental space for interaction, but it does not attempt a thorough investigation into their role mainly due to the imposed length limit of this thesis. Notwithstanding, the following paragraphs examine briefly the role of virtual media in the form of ICT mainly in relation to the primary research framework, Nonaka's framework, and the case organization.

ICT often contributes decisively to the success of knowledge management projects (Davenport et al. 1998; Scarbrough at al. 1999) and to assisting knowledge creation, storage and retrieval, transfer, and application processes (Davenport et al. 1996; Alavi and Leidner 1999; 2001). Hence, ICT transfers internal knowledge (O'Dell and Grayson 1998), captures the process

[22] Small core group with own identity similar to a community of practice (Wegner 1998)

context with knowledge repositories (Earl 1994a; Davenport et al. 1998; Ruggles 1998), supports collaboration with decision support tools and groupware (Grudin 1987; 1994; Bannon 1998; Ciborra and Patriotta 1996; Orlikowski 1995; 1996; Malhotra and Majchrzak 2004), maps internal expertise sources and allows knowledge dissemination (Daniels 1994; Ruggles 1998; Stenmark 2000), creates and manages knowledge assets (Boisot 1998), and facilitates the learning of knowledge work (Spitler and Gallivan 1999).

However, the use and the role of ICT for knowledge processes also has limitations and cannot deliver wonders (Boisot 1998; Malhotra 1998; Grudin 1988; Purvis et al. 2001) when, for example, there is lack of a coherent knowledge management strategy (Earl 2001), when pre-existing tacit knowledge prevents its collaborative nature (Orlikowski 1992), when existing learning processes influence its implementation (Scarbrough 1998), and when intranets are used for the reinforcement of existing functional boundaries (Newell et al. 2001).

The social constructionist perspective of the Unified Model of Dynamic Knowledge Creation also shapes its view of ICT, which is considered as a social object, within knowledge creation. Thus, individuals and groups shape both the design and adoption of ICT depending on their interests and perspectives, with some obvious contextual limitations (Newell et al. 2002). The adoption of the concept of Action-Reflection-Trigger (ART) systems points out that ICT could facilitate the knowledge creation process mainly through the creation of various types of Ba (Nonaka et al. 1998a). Using Davis and Nauman's (1999) distinction of ICT for knowledge work, ART systems could be divided into tools that enhance the productivity of individuals, and into applications for coordination, communication, and the management of knowledge. Appendix Two adapting Davis and Nauman's (1999) table for the potential role of ICT to knowledge work illustrates how ICT could contribute to the knowledge creation process of the maintenance case organization.

More specifically, within the case organization, the Computerized Maintenance Management System (CMMS) could promote the building of Ba by becoming the virtual collaborative platform (Laudon and Laudon 1994; Ciborra 1996; Galliers and Baets 1998; McLeod 1998; Kendal 1999) for externalizing, capturing, sharing and disseminating knowledge, and for supporting knowledge work (Kelly 1997a; Lalib 1998; Pintelon 1999). The CMMS integrates a wide range of associated business functions and modules, which makes it an example of a synergetic solution between an ERP System and a Knowledge Management System (Huang et al. 2001), while it performs its role by utilizing databases, computer tools and query facilities, and by performing transactions (UNIDO 1994).

2.9 Building, connecting and energizing Ba

The management of the knowledge creation process can be achieved through building, connecting and energizing Ba. This can be built either intentionally, as with the creation of a maintenance repair team, or spontaneously, when for example workers socialize (Nonaka and Konno 1998). The intentional building of Ba, depending on the circumstances, requires the provision of physical space, such as meeting rooms, virtual space, such as a computer network, or mental space such as a vision, common goals and a careful selection of participants, which can boost interactions. In contrast, the discovery and utilization of spontaneously formed Ba, which changes or disappears very quickly, depends on management's perception in recognizing interactions (Nonaka et al. 2001a). Moreover, since Ba exists at many levels, which often connect with each other to form a greater Ba that is known as Basho (Nonaka and Konno 1998: 4), interactions among themselves and among their participants, which are not predetermined, should be recognized and facilitated (Nonaka and Konno 1998).

In addition, it is important that Ba is stimulated or energized in order to give energy and quality to the SECI process. Such stimulation occurs through the conditions of autonomy, creative chaos, information redundancy, requisite variety, and care, trust and commitment (Nonaka et al. 2001a). Without neglecting the importance of building and connecting Ba, the present thesis seeks to explain the contribution of these conditions upon the knowledge creation process through their influence on Ba interactions and consequently on individual and group roles. A review of these "knowledge-enabling conditions" (Nonaka 1994) follows.

2.9.1 Autonomy

The issue of autonomy occupies a central place in the literature on knowledge work (Davenport et al. 1996). For the knowledge creating organization, autonomy is important, since it motivates, commits, and increases the chances, for both individuals and teams, of finding, accessing and utilizing valuable and often unexpected knowledge (Nonaka 1994; Grant 1996a; 1996b). Furthermore, autonomy promotes the creation of concepts and the cross-levelling of knowledge (Nonaka and Takeuchi 1995), but this depends, amongst other factors, on both individual commitment and on the dynamics of team-building and team operation (Badaracco 1991; Sinclair 1992; Drucker 1993; Introna 1997; Newell et al. 2002).

A common way for the promotion of autonomy within organizations is the functioning of self-organizing teams (Varela 1984; Nonaka 1994), which can also be depicted as "autopoetic systems" (Von Krogh and Roos 1995). The present thesis views knowledge creation as "an interactive teamworking process – one which involves a diverse range of actors with different backgrounds, cutting across organizational boundaries, and combining skills, artefacts, knowledge and experiences in new ways" (Newell et al. 2002: 48). For this reason, and due to the importance of the social processes of dialogue and interaction in groups in energizing Ba, it focuses on the role of autonomous maintenance teams within the case organization.

An autonomous team, amongst other things, decentralizes decision-making (Nishiguchi and Beaudet 2000), deals with the hurdles and cascades of information (Brown and Duguid 2000), amplifies individual perspectives and transforms them into collective perspectives, draws upon a larger pool of knowledge and perspectives, increases the acceptance and the commitment of decisions, promotes socialization, and reduces time and cost (West et al. 1998; Ivancevich and Matteson 1999; Newell et al 2002). However, in order to be capable of achieving its goals, the team should have access to resources, should include a sufficient range of skills, and should be empowered with decision-making authority (Mainz et al. 1990; Owens 1991; Daft 1995). Cross-functional autonomous teams may also boost innovation processes (Nonaka et al. 2000a).

Autonomous teams, similar to communities of practice, can extend across the boundaries of business units, but they should not be confused with them, since the latter are often unrecognized and connected by a shared interest in contrast to autonomous teams, which are mainly institutionalized and connected by interdependent tasks (Wegner et al. 2002).

The conformity of a team, group polarization and groupthink (Janis 1982; Newell et al. 2002) are often issues associated with energizing the Ba of autonomous teams, since for example, autonomous individuals and groups are more likely to achieve the desired level of conformity because they set their own task boundaries. In addition, polarized groups can pursue more ambitious goals, while the excessive conformity of groupthink minimizes the input of new ideas by individuals.

Moreover, the distribution of power and responsibility and the existence of mechanisms of control in autonomous teams are also important for their smooth functioning (Badaracco 1991; Sinclair 1992; Introna 1997; Newell et al. 2002). Many of the problems associated with the functioning of a self-organized team can be resolved with the existence of proper team integration mechanisms. Newell et al. (2002), in extending Grandori and Soda's (1995) work, argue that important team integration mechanisms include access to communication channels, coordination through agreed norms and incentive systems, the assignment of responsibilities and authority to individuals, and the careful selection of team members.

2.9.2 Creative chaos

The present research is also concerned with the causes of a sense of crisis in Ba interactions within the knowledge creation process of the case maintenance organization and explains them by using the concept of creative chaos. Creative chaos stimulates Ba interactions between the organization and the external environment and widens the spectrum of options promoting innovation, since it forces the organization to seek new points of view (Nonaka 1988a). Creative chaos can also be stimulated by the deliberate proposal of challenging goals, by ambiguous visions, or by market and technological discontinuities that cause an artificial crisis (Tushman and Anderson 1986; Nonaka 1988a). Such crisis situations cause breakdowns of routines, habits and cognitive frameworks, enable individuals to focus attention on framing and resolving problems (Kim and King 2004) and provide opportunities for fundamental rethinking. The questioning and re-evaluation of existing premises energises Ba interactions, influencing in particular the creation of concepts, through a mechanism of enacted sensemaking (Weick 1988; 1993). Some name this as "order out of noise" or "order out of chaos" and argue that it demonstrates self-organization (Von Foerster 1984; Peters 1987). However, leaders should be able to read the situations for the introduction of creative chaos in the right place at the right time, so that the organization does not fall into complete disorder (Nonaka et al. 2001a).

The concept of creative chaos has basic similarities with the notion of creative abrasion (Leonard 1998), which explains that the energy generated by conflicts can be channelled into creating rather than fragmenting. Creative abrasion can also be perceived as one form of constructive confrontation among individuals purposefully oriented towards the synthesis of their diverse perspectives that promotes the different framing and resolution of a problem (Leonard 1998).

Furthermore, the concept of creative chaos is closely related to the concept of creative tension (Fritz 1989; Senge 1990b), according to which the distance between a clear stated vision and the current reality generates tension that can be resolved in two basic ways, either by raising current reality toward the vision, or by lowering the vision toward current reality. When individuals and teams learn to work with creative tension, they start using the generated energy to transform a reality towards the vision. Without a vision there is neither creative tension nor creative chaos. Leading through creative tension is different than problems solving, due to the fact that problem solving is an attempt to get away from an unwanted aspect of the current reality. In the case organization reactive maintenance is such a problem-solving example, where personnel attempt to get away from an unwanted aspect of current reality. This is perhaps an indication that Ba interactions in such situations are not stimulated by real creative chaos. In contrast to mere problem solving, the energy and the motivation for change in both creative tension and creative chaos are intrinsic (Senge 1990b).

2.9.3 Redundancy of information

The condition of "information redundancy" refers to the intentional overlapping of information about business activities, management responsibilities or the company as a whole that goes beyond the immediate operational requirements of organizational members (Nonaka and Takeuchi 1995). Information redundancy has a reassuring character for individuals, since it affects their "preparedness to believe" (Dretske 1981: 116) and provides a background for building and energizing Ba interactions in a twofold way (Nonaka et al 2001a).

First, information redundancy promotes the sharing of tacit knowledge across boundaries opening a dialogue between inside and outside perspectives (Nonaka 1990; Wegner et al. 2002). As a result, it is easier for individuals to grasp what fellow colleagues are trying to say, for example, during investigations of maintenance problems. However, the sharing of redundant information, often with the use of information systems, such as groupware applications (Ciborra 1996a), does not necessarily ensure the sharing of experiences and tacit knowledge (Baumard 1999). Trust is also necessary since it facilitates individuals offering advice and providing new information from different perspectives (Nonaka 1990). The importance of information redundancy becomes evident especially during organizational change programmes, when large numbers of employees become redundant and gaps of know-how and skills are created (Von Krogh and Kameny 2002).

Second, redundancy of information helps organizational members understand their role in the team and in the organization and therefore achieves control through the direction of the individual's thinking and actions (Nonaka 1994). It also affects a team's absorptive capacity, which is the capacity to recognize the value of new, external information, absorb it, and apply it productively (Cohen and Levinthal 1990). Moreover, redundant information strengthens inter-organizational relationships, such as between an organization and its suppliers, thereby energizing collective types of Ba, which require the dynamic cooperation of many different groups (Nonaka and Takeuchi 1995; Avadikyan et al. 2001; Belussi and Pilotti 2002).

The dark side of redundant information is connected to its potential to increase the amount of data to be processed, which can lead to information overload (Nonaka et al.2001a). As Burton-Jones (1999: 219) expresses it: "Information is not the problem, understanding is. Society is drowning in information, but still left thirsty for knowledge". Another potential problem is the increased cost of knowledge creation, at least in the short run (Dretske 1981). Management should read situations and deal with the possible downsides of information redundancy by making clear where knowledge is located and stored (Nonaka 1994; O'Dell and Grayson 1998).

However, and despite its recognized importance at a theoretical level (Dretske 1991; Nonaka 1994; Wegner et al. 2002), the realization of the condition of information redundancy as an enabler of knowledge creation requires empirical support (Baumard 1999). The present research focuses on the role of information redundancy within the knowledge creation process by looking at job rotation of employees in different positions and roles within the case organization, since this tactic allows them to gain additional technical and managerial knowledge and skills (Nonaka 1994).

2.9.4 Requisite variety

The condition of requisite variety regulates the equilibrium between "order and chaos" (Nonaka et al. 2001a), since as the definition, based on Ashby (1957), states: "Only variety can absorb variety" (Beer 1985: 30). Hence, requisite variety achieves organizational integration and coherence and drives adaptation to environmental fluctuations and market changes through the embracement of an organization's internal diversity. It is considered important in collective Ba interactions, especially during the building of the archetype in the knowledge creating process (Nonaka and Takeuchi 1995). The potential of requisite variety to change organizational reality connects it to the notion of creativity as an organizational aptitude (Vicari and Triolo 2000). The different, flexible and quick combination of information, very often though experimentation (Leonard 1998; Vicari and Triolo 1998) and computer simulations (Stacey 2001), and the provision of equal access to information throughout the organization can enhance requisite variety (Nonaka and Takeuchi 1995). Furthermore, it is also promoted through intra-firm collaboration (Badaracco 1991; Patel and Pavitt 2000). From a theory of a firm perspective, requisite variety can be enhanced by acquiring organizational combinative capabilities (Kogut and Zander 1992; Koruna 2004).

For the shaping of the condition of requisite variety an organization not only has to generate variety internally, but it also has to communicate this variety (Introna 1997). Lack of appropriate communication contributes to the creation of information differentials, which contribute to the shaping of power relationships, preventing interaction on equal terms, since there is mostly one-way dependence, rather than interdependence (Sheppard and Sherman 1998). Furthermore, employees should know where information is located and how this information and knowledge can be accessed (Nonaka 1994).

However, and despite the recognition of the importance of the condition of requisite variety in knowledge processes, little empirical work has been made in this regard. An exception is Lessem (1998) and Lessem and Palsule (1999), which provided a concise case study about knowledge creation at Surrey Police, from a managerial development perspective. The present thesis attempts to cover this research gap by examining at least two ways for the realization of requisite variety (Nonaka 1994; Lessem 1998; Lessem and Palsule 1999). First, the thesis examines whether the case organization has a flat and flexible organizational structure, or business layer, and whether the existent information network is capable of providing individuals with fast and equal access to vital information (Peters 1987; Nonaka et al. 2001a; Hansen 2002). A flat organizational structure can promote requisite variety by ensuring fast access to a broad variety of information, since not only can it improve communication, but it can also increase autonomy and therefore employees reach the information source without many restrictions. Literature indicates that information technology has an enabling role for the creation of a flat organization (Brown and Duguid 2000), while in practice flatter structures usually occur with the removal of middle management levels (Newell et al. 2002), whose role is considered as important for the knowledge creation process.

Second, the thesis examines whether requisite variety is realized through the provision of opportunities for the different, flexible and quick combination of information, which can be given through frequent changes in organizational structure, through frequent rotation of personnel or even through technological discontinuities. Such practices, when coupled with the communication of information, ensure that employees acquire interdisciplinary knowledge and increase the possibilities that they will cope successfully with environmental or organizational complexity. Additionally, empirical evidence supports that technological discontinuities can enhance employee competencies and promote requisite variety (Tushman and Anderson 1986). Such technological discontinuities provide opportunities for improvements not only in products but also in organizational routines.

2.9.5 Care, trust and commitment

This thesis is also concerned with energizing Ba interactions through fostering care, trust and commitment amongst organizational members (Nonaka 1994; Von Krogh 1998), which, among other things, promote the knowledge sharing and the self-transcendence of the knowledge creation process (Scharmer 2001). Care, trust and commitment, which are also considered as intangible experiential knowledge assets, are seen as important conditions for the energizing of interactions throughout the knowledge creation process (Nonaka 1994).

Von Krogh (1998: 13) defines care as "serious attention, a feeling of concern and interest" and argues that it gives rise to relationships of mutual trust, active empathy, access to help, lenience in judgement, and courage for individual verbal expression or expression during action, including experimentation or improvisation. Such relationships are present in the Styhre et al (2002) study of a pharmaceutical company, which shows how care positively affected the knowledge-intensive activity of product development. In contrast, low care relationships require a demonstration of expertise and clear and legitimate expressions of explicit knowledge. The application of means such as unconventional language, storytelling, analogies, or metaphors, which are important for knowledge creation, is difficult in low care relationships. Care can be fostered within an organization with the creation of an incentive system, mentoring and training programmes, project debriefings, social events, and the expression of trust and openness as corporate values (Von Krogh 1998).

The delineation of care relationships at the different stages of the knowledge creation process within the case organization is attempted in this thesis with the use of a framework developed by Von Krogh (1998). The characteristics of this framework, which associates knowledge creation processes at the individual and the social level with high and low care organizational relationships, are presented in Figure 2.4. The suitability of this framework is not only limited to the fact that it is useful for interactions at both the individual and the collective levels, but also extends to the fact that it describes in detail the knowledge creation process under the influence of high or low care, relationships allowing associations with different types of Ba.

Figure 2.4 **Care in Knowledge Creation Processes**

Low care organizational relationships		
Level	**Knowledge Creation**	**Process Characteristics**
Individual	**Knowledge Capturing**	• Individual search for "maximum grip" • No interest/attempt to share knowledge • Limited feedback from others • Isolation of individual
Social	**Knowledge Transactions**	• "Experts" transacting their knowledge • Minimizing risk of conveying non-legitimate knowledge • Sharing based on expected returns • Knowledge shared is the end result of a "maximum grip" learning process
High care organizational relationships		
Level	**Process**	**Process Characteristics**
Individual	**Knowledge Bestowing**	• Knowledge created in a supportive environment • Strong intent to share knowledge on the future • Feedback and active help from others, creation of a supportive environment • Integration of individuals into the team

Figure 2.4		Care in Knowledge Creation Processes
Social	Knowledge Indwelling	• "Equals" creating knowledge • Questioning and changing the basis of legitimate knowledge • Sharing to help the team grow • Attempts to "look with" not "look at" other team members • Important for the sharing of tacit knowledge and for concept creation • Commitment to the team is a fundamental quality

Adapted from Von Krogh (1998: 143)

Besides care, trust is also another important condition that energizes Ba, for which many definitions have been proposed (Ring and Van de Ven 1992; Newell et al. 2002). However, a generally acceptable definition is that trust means "the willingness of a party to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party" (Mayer at al. 1995: 712). The existence of trust is often indicated though the existence of cooperation, confidence and predictability, however these concepts should not be considered as identical with it (Mayer at al. 1995).

Literature indicates the existence of various types of trust (Shapiro et al. 1992; Ring and Van de Ven 1994; Meyerson et al.1996; Jones and George 1998) and the existence of a number of frameworks for the description of their development. For example, Mayer's et al. (1995) framework focuses mainly on trust at the individual level and this limits its application in processes of knowledge creation, which often involve collective interactions.

Trust regulates how and why organizational knowledge develops (Huemer et al. 1998) and creates coherent Ba by promoting cooperation and teamwork (Badaracco 1991; Ring and Van de Ven 1994; McAllister 1995; Jones and George 1998). Low-trust groups face problems in goal clarification, information exchange, commitment, distribution of power and authority and the implementation of solutions (Zand 1972; Shapiro 1987; Brockner et al. 1997). Managers with trustworthy behaviour appear to be important trust initiators (Whitener et al. 1998). Trust is dynamic and may change according to the existing conditions (Rousseau et al. 1998) both in cases of socialization interactions (McKnight et al. 1998) and in collective and virtual Ba (Jarvenpaa and Leidner 1999). Furthermore, trust affects both internalization (Edmondson and Moingeon 1999; Wegner et al. 2002) and improvisation (Ciborra 2002).

The present research uses the typology that categorizes trust into companion, competence and commitment trust (Newell et al. 2002). The characteristics of each type of trust are shown in Figure 2.5. This typology not only enables the identification of different types of trust at the different stages of the knowledge creation process, but it also helps describe their development process. Thus, for example, companion trust is developed primarily during socialization. Moreover, the selection of this particular typology enables the association of trust with both individual and collective types of Ba. Furthermore, this typology is broader than pre-existing frameworks on trust (Mayer et al. 1995), since it manages to integrate different and diverse perspectives, and provides a connection with Von Krogh's framework (Von Krogh 1998) on care.

Figure 2.5 A Framework for Examining Trust in Knowledge Creation Processes

	Companion Trust	Competence Trust	Commitment Trust
Based on	Judgments of goodwill, personal friendships. Moral foundation.	Perceptions of the competencies of partners. Respect for the abilities of the trustee.	Contractual agreements
Expectations	Mutual honesty and openness. Lenience in judgements. Maintains social networks.	The truster feels that they can rely on the trustee.	Mutual benefit. Others can be trusted to put in the effort necessary to complete the joint work.
Formation	Process-based trust. Slow development through socialization.	Interpersonal exchange not necessary. Competence judgments are often driven by contextual cues. Develops swiftly.	-
Type of trust	Resilient	Fragile	More resilient than competence trust - Less resilient than companion trust
If broken	Causes the greatest rift		Excludes future collaborations

Based on Newell et al. (2002)

Finally, adjacent to the roles of care and trust as energizers of Ba, comes the role of commitment (Nonaka and Takeuchi 1995). Commitment is often defined as loyalty to a social unit, where the social unit may be an organization, the subsystem of an organization, or even an occupation (Price 1997). Commitment gives direction to organizational activities (Nonaka 1994; Price 1997; Rasmussen 2004).

The present thesis endeavours to associate the knowledge creation process with why it is that individuals commit to it. Literature demonstrates, amongst others, that the compatibility of personal values with organizational values (Kalleberg et al. 1996), career development prospects, job design and organization, and the provision of financial incentives (Blau et al. 1993; May et al. 2002) are some of the most common factors that influence commitment. All the above-mentioned factors shape intention, which in its turn stimulates commitment. The role of intention as a factor that generates commitment in knowledge creation processes is important since it enables individuals to judge the value of information or knowledge perceived or created (Nonaka 1994). Furthermore, the role of middle management is important in the fostering of commitment in each stage of knowledge creation (Naito 2001).

2.10 Knowledge assets: definitions and related literature

Nonaka's framework attracted early criticisms for being grounded in the academic discipline and consequently for failing to make managerial use of the concept of knowledge (Boisot 1998), for providing a framework with no applicability in action, similar to quality tools (Garvin 1993), and for using engineering terminology (Lessem and Palsule 1999). In addition, the framework treats the influence of power relationships (Foucault 1980; Scarbrough and Corbett 1992; Introna 1997; Larsen 1997) to knowledge creation only implicitly. The issue of the framework applicability has been overcome with the adoption of the concept of knowledge assets, which appears in market-oriented perspectives on knowledge management (Grover and Davenport 2001). Skyrme (2001) argues that knowledge assets can be used in management since they allow measurements.

From a market perspective (Grover and Davenport 2001), knowledge has started to be viewed as an asset in its own right and not only as an enhancement of other kinds of assets. Thus, knowledge assets, or intellectual assets, are economic assets in their own right. Knowledge assets are defined as "anything valued without physical dimensions that is embedded in people or derived from processes, systems and the culture associated with an organization" (Bukowitz and Williams 1999: 2). Other definitions focus on the usability of knowledge assets explaining that these are stocks of knowledge that allow the organization and the provision of services for an unspecified period of time (Boisot 1998; Teece 1998). Knowledge assets are intangible and different from physical assets in several aspects, since they can be used by many parties, they are depreciated rapidly, but they do not wear out, they are hard to calibrate, while they are often limited by patents and trade secrets (Teece 2000).

Nonaka places knowledge assets at the base of knowledge creation processes, explaining that they are the processes' inputs, outputs and moderating factors (Nonaka et al. 2000b). Thus, knowledge assets comprise the content of each knowledge creation process and the process determines how they are built (Nonaka et al. 2000b). This property makes them indispensable firm-specific resources that create value for the firm (Nonaka et al. 2000a). However, they are often invisible, tacit and dynamic (Nonaka et al. 2000b) and this makes the capturing of their value difficult (Nonaka et al. 2000a), similarly to the economic perspective (Teece 1998; 2000a;

Boisot 1998) where discrepancies between market and book value in many knowledge-intensive companies are often perceived (Skyrme 2000). Nevertheless, knowledge assets can be quantified and can define a firm's boundary.

Since knowledge assets cannot always be readily bought or sold they shape a firm's competitive advantage (Teece 2001; Nonaka et al. 2000b). However, their creation and use conceals complicated processes surrounding the integration of intangible and tangible assets, and the transfer of intangible assets inside the firm (Teece 2001). Moreover, and despite the recognition of the fact that depending on the firm strategy, different processes concerning knowledge assets, such as knowledge creation or knowledge transfer may be favoured (Von Krogh et al. 2000a), the actual transfer or creation process is somehow missing from the literature.

According to the Unified Model of Dynamic Knowledge Creation, there are four types of knowledge assets corresponding to the four stages of the knowledge creation: experiential knowledge assets, conceptual knowledge assets, systemic knowledge assets and routine knowledge assets. Since the present research aspires to explain the interrelationships of the knowledge creation process with its context and its content, an in-depth examination of these knowledge assets is useful due to the fact that they define the content of this process within the case organization. Hence, recognizing that on the one hand it is relatively difficult to monitor and measure some types of knowledge assets (Skyrme 2000; Nonaka et al. 2000b; Teece 2001), especially those closely associated to the tacit nature of knowledge (Nonaka et al. 2000b), and on the other that it is not within the scope of this thesis to provide a detailed account of all knowledge assets within the knowledge creation process, the following sections attempt, amongst others, to delineate how the knowledge asset concept is used within this investigation. However, such an approach requires an indicative selection of knowledge assets in relation to their apparent importance to the case organization.

2.10.1 Experiential knowledge assets

Experiential knowledge assets consist of the shared tacit knowledge that is built through shared hands-on experience amongst the members of an organization, and between the organization and its customers, suppliers and affiliated firms (Nonaka et al. 2000a; Nonaka et al. 2001a). Their tacit nature not only makes efforts to capture, measure, evaluate or trade difficult, but also makes them firm specific, difficult to imitate resources that can lead to a competitive advantage. Hence, organizations need to build their own knowledge assets through their own experiences.

The experiential knowledge assets of skills and know-how that are acquired and accumulated by individuals through experiences at work are of particular importance to the present research, since the knowledge-routinized and an expert-dependent case organization (Blackler 1995) depends on them for the performance of the tasks at hand. Hence, the research attempts to explain not only how these are acquired by maintenance personnel, but also how they are used in the various stages of the knowledge creation process.

Skills define the competence of individuals (Zander and Kogut 1995). They can be learnt through apprenticeship and experience, since they cannot easily be explained in words. Skills can only be demonstrated (Drucker 1993). "Skilful performance is achieved by the observance of a set of rules which are not known as such to the person following them" (Polanyi 1962: 49).

The process of building the experiential knowledge asset of skill follows a common pattern from rule-guided "knowing that" to experience-based "know-how" and normally involves five stages[23] (Dreyfus and Dreyfus 1986). Individuals at the first stage, namely the novice stage, can only participate at the socialization stage of knowledge creation by accumulating knowledge. Individuals need to reach the advanced beginner's stage of competence in order to involve themselves actively in the other stages of the knowledge creation process. This presupposes that they have accumulated considerable experience in coping with real situations and they are able to make use of the metaphor/analogy mechanism (Dreyfus and Dreyfus 1986). As skill acquisition moves to the later stages, individuals acquire an experienced perspective and decision-making becomes more intuitive and less analytical (Dreyfus and Dreyfus 1986). In addition, individuals become increasingly involved in the situation (Dreyfus and Dreyfus 1986), since they have acquired difficult to duplicate firm-specific skills (Leonard 1998).

The skill acquisition process is influenced both by the existence of a personal vision and the communication of a common organizational vision (Senge 1990b). In addition, skill acquisition requires the testing of an individual's mental models (Senge 1990b). Individuals that integrate diverse knowledge sets and have the ability to see the world from many different perspectives can test their mental models by taking an opposing view to so-called solutions to problems, or by resisting the development of signature skills (Leonard 1998), by resisting the creation of a tunnel vision (Dreyfus and Dreyfus 1986), and by maintaining their creativity.

In addition, the experiential knowledge asset of know-how is linked to the skill acquisition process. Thus, know-how is the ability of an individual or a team to perform a certain kind of

[23] These stages are: the novice stage, the advanced beginner stage, the competent stage, the proficient stage, and the expert stage.

activity or task smoothly and efficiently (Machlup 1980) and requires the accumulation of practical skill or expertise. It must also be learnt and acquired (Kogut and Zander 1992), while practice is required for its maintenance (Dreyfus and Dreyfus 1986).

Besides the knowledge assets of skill and know-how, the present thesis is also concerned with the experiential knowledge asset of improvisation (Nonaka et al. 2000a; Nonaka et al. 2001a), due to its importance in maintenance organizations particularly during the scheduling and the execution of maintenance work, which are typical activities in the combination and internalization stages.

The notion of improvisation[24] arises in varied contexts, while many definitions have been proposed for the term. Improvisation is the degree to which composition and execution converge in time (Moorman and Miner 1998). It is also a situated action (Orlikowski 1996; Ciborra 2002) usually executed by an individual, but it can also occur at a collective level through conversation amongst individuals (Moorman and Miner 1998). Improvisational actions require the individual to be in the mood to act (Ciborra 2002). Such actions involve the reworking of precomposed material and designs in relation to unanticipated ideas conceived, shaped, and transformed under the special conditions of performance, thereby adding unique features to every creation (Weick 1998). A key characteristic of improvisation is that individuals take different leads at different times, but this requires the creation of a nurturing environment and the creation of a team able to cooperate and embrace the improvisers (Crossman 1998). In addition, the literature reveals that improvisation often correlates with other features of action that may or may not be present, such as bricolage[25] (Levi-Strauss 1967), intuition[26] (Dreyfus and Dreyfus 1986; Crossan and Sorrenti 1997; Ciborra 1997; 2002) and creativity[27] (Moorman and Miner 1998).

Furthermore, improvisation requires an interpretation of the environment through the expansion of individual and organizational abilities to perceive opportunities and threats, which should be reflected in the pattern of actions of the organization, namely its strategy (Crossman 1998). The platform organization provides such an environment for improvisation (Ciborra 1996b; 1997). Therefore, improvisation is also perceived as a specific kind of adaptation and it is often seen as

[24] Improvisation can be seen from an organizational (Schon 1983; Preston 1991; Weick 1993; 1996; Crossan and Sorrenti 1997; Ciborra 1999b), a musical (Chase 1988), a theatrical (Knapp 1989), a therapeutical (Gardner and Rogoff 1990), and an educational perspective (Yinger 1986).

[25] Bricolage is defined as "making to do with the materials at hand" (Levi-Strauss 1967).

[26] Intuition means operating when choices are made without formal analysis or planned decision-making process.

[27] Creativity involves a degree of novelty or deviation from standard practice.

a form of innovation, since it involves some kind of creation. Improvisation is an important factor in knowledge creation, not only due to its focus on tacit knowledge (Weick 1993), but also due to the fact that improvisational actions can serve as unplanned experiments generating changes in an organization's procedural and declarative memory (Moorman and Miner 1998; Leonard 1998) and facilitating learning when it is coupled with reflection and assessment (Moorman and Miner 1998). Furthermore, the experiential knowledge asset of improvisation depends on the existence of the knowledge asset of individual skills (Crossman 1998).

In general, there is agreement about the existence of a spectrum of various types of improvisation. For example, Weick (1998) uses the jazz metaphor to describe the existence of four types of improvisation. Others differentiate between smart or competent improvisations that contribute to individual and organizational effectiveness (Ciborra 1999b) and less smart improvisations, the latter being connected to negative notions of knowledge, such as unwanted knowledge (Machlup 1980).

The present research approaches improvisation within the case organization mainly by using Moorman and Miner's (1998) three levels of improvisation, since these are easily adapted to common situations within maintenance organizations. Thus, the first level of improvisation involves modest adjustments to a pre-existing piece or process. A similar level of improvisation within the case organization is the rescheduling of repairs or the performance of minor modifications to a piece of equipment during a repair. Moorman and Miner (1998: 703) use the jazz metaphor to explain the second level of improvisation: "A second level of musical improvisation involves stronger departures from the referent or underlying song. Organizational examples of this level of improvisation include improvised new products that represent variations on existing products or production processes". Orlikowski (1996) presents a case in which a series of first-level improvisations resulted in the substantial improvement of work routines over a period of time, indicating that the above-mentioned levels of improvisation are not in isolation or unique. The third level of improvisation is one in which "the improviser discards clear links to the original referent and composes new patterns. [...] In organizations subgroups may create a new product not only outside of, but actually inconsistent with, existing firm strategy" (Moorman and Miner 1998: 703).

Finally, and besides skills, know-how and improvisation, other experiential knowledge assets that concern the present thesis include care and trust, due to their importance in professional service organizations (Newell et al. 2002; Von Krogh 1998; Carlsen et al. 2004). Both their role and importance within the knowledge creation process and the frameworks that are used for their examination in the present research have already been described in a previous section.

2.10.2 Conceptual knowledge assets

Conceptual knowledge assets consist of explicit knowledge articulated through images, symbols and language. They are based on the concepts held by members and customers of an organization (Nonaka et al. 2000a) and are often thought of as information complexions that represent generic concepts, such as objects, situations, events, actions, and sequences of actions that are known tacitly by individuals (Boisot 1995). From a systems perspective (Checkland 1999: 169) a conceptual knowledge asset is seen as a model, an account of the activities undertaken to enable the system to exist. In contrast to experiential knowledge assets, they have tangible forms, hence they are easier to grasp, and since they have no particular habitat, they can be easily articulated (Boisot 1995) and engineered.

Conceptual knowledge assets are created by the generation and articulation of ideas (Doyle 1999; Sen 2004), such as during the new product development process (Scarbrough and Corbett 1992; Doyle 1999; Fong 2003; Roth 2003). This creation process requires both stimulation and focus (Scarbrough and Corbett 1992). Moreover, brand equity and concepts or designs, as perceived by customers and organization members, are also conceptual knowledge assets (Nonaka et al. 2001a). Since conceptual knowledge assets are created with the use of images, symbols and language, not only the existence of a language known and accepted by all participants, but also conversation and its content, its style and its management are important (Von Krogh and Roos 1995; 1996; Von Krogh et al. 2000a). For example, Westley (1990) highlights the decisive role of middle management in conversations about the development of conceptual knowledge assets concerning the formulation of strategy. In addition, Von Krogh and Roos (1995) distinguish between operational and strategic conversations within organizations.

Furthermore, the creation of conceptual knowledge assets becomes more effective with the encouragement of participation, the application of rules and the assignment of an appropriate conversation etiquette, the "editing" of the conversation and the use of innovative language (Von Krogh et al. 2000a). The literature demonstrates that the articulation of ideas and the formulation of concepts occur either in an unstructured way, such as during a casual conversation, or in a structured way, such as with the use of focus groups, mindmapping or questionnaires (Butler 1996; Von Krogh et al. 2000a; Sen 2004). Usually, an individual's ideas are transformed into concepts with the inclusion of details regarding the product or service form, its function, the need that will become satisfied, and the potential advantages (Slack et al. 1998). For example, the procedure through which the Customer Support Department of Zeta

Corporation records software users' problems (Orlikowski 1996) is a typical case of a structured way for the creation of conceptual knowledge assets. In this case, the incident form, which captures explicit language that describes the software problem, is the tangible conceptual knowledge asset.

The present research explores conceptual knowledge assets using a similar example of documents that contain the concepts about the maintenance repairs. In the case organization, the externalization stage and the creation of a conceptual knowledge asset commence with the oral or written request of a machine operator for maintenance work (Wireman 1990; Kelly 1997a; 1997b; Levitt 1997). Then, based on explicit knowledge of the machine fault, participants discuss the course of action that needs to be taken for the repair. This is usually recorded on an official document, the Maintenance Work Order Form or Work Order[28] (WO) (Wireman 1990; Kelly 1997a; 1997b; Levitt 1997). In this case the information system for the management and control of the maintenance workload is the Maintenance Work Order System (MWOS). When this workload system is viewed from a process perspective and maintenance work is seen as knowledge work that both utilizes and creates knowledge (Davenport 1995; Davenport et al. 1996), this provides a structured way for the articulation of ideas and the formulation of concepts for externalization (Butler 1996). The MWOS also establishes a communication channel for interactions (Von Krogh et al. 2000a). A concern of this thesis is the manner in which the Work Order form and the MWOS contribute to the creation of maintenance knowledge.

2.10.3 Systemic knowledge assets

Systemic knowledge assets consist of systematized and packaged explicit knowledge, such as explicitly stated technologies, product specifications, manuals, reports, licenses, contracts, patents and documented and packaged information about customers and suppliers (Nonaka et al. 2000a; Klint and Verhoef 2002; Nakhla 2003), which makes them easily transferable. Systemic knowledge assets can also be quantified relatively easily and therefore their flows can be measured (Boisot 1998), in contrast to other less tangible types of knowledge assets (Miles et al. 1998; Sveiby 2000). Thus, since this kind of knowledge asset is the most "visible", often the focus is primarily on its storage, retrieval, access and management. Knowledge repositories and databases often occupy a central role in their management.

[28] The Work Order is a document, a tangible asset that captures and articulates the explicit knowledge of a maintenance repair via written language.

Databases are also considered as systemic knowledge assets synthesized by fragments of explicit knowledge in a particular structure with explicit rules (Alavi and Leidner 1999; Blair 1984; Davenport et al. 1996; Zack 1999). Besides an examination of a database, similar to Zeta Corporation's ITSS call database described by Orlikowski (1996), which contains explicit information about the approved and executed maintenance works (Wireman 1990; Kelly 1997a; 1997b; Levitt 1997), the present research focuses on the role of systemic knowledge assets within the maintenance knowledge creation process using the example of the asset register database, which contains information about the maintainable equipment of the organization. Thus, the thesis examines how this database along with a number of other knowledge assets, such as reports, contribute to the creation of an important systemic knowledge asset, the maintenance job plan[29], which consists of explicit maintenance and other technical knowledge about the execution of the maintenance repair (Wireman 1990; Kelly 1997a; 1997b; Levitt 1997).

2.10.4 Routine knowledge assets

Routine knowledge assets consist of the tacit knowledge that is routinized and embedded in the patterns of thinking, the practices and the actions of organizational members through continuous exercises (Nonaka et al. 2001a; Nonaka et al. 2000a). The formation of routine knowledge is also facilitated when members share a common background and history. Know-how, organizational culture and organizational routines for carrying out the day-to-day business of the organization are examples of such knowledge assets, which concern the present investigation. For these knowledge assets, the literature demonstrates the existence of important empirical research, but does not link them to broader processes of knowledge creation.

The notion of organizational routines has attracted much interest since the late 1960s (Cyert and March 1967), as part of the evolutionary theory of the firm (Nelson and Winter 1982) and an organizational capabilities perspective (Prahalad and Hamel 1990; Nelson 1991; Narduzzo et al 2000). Routines in organizations are the equivalent of individual skills and they are formed by a tacit and collective type of knowledge (Nelson and Winter 1982; Matusik and Hill 1998). However, they are different[30] from organizational processes (Cohen and Bacdayan 1994; Teece et al. 2000). Organizational routines are necessary along with information flows (Davenport 1993) in order to set organizational processes in motion (Brown and Duguid 2000).

[29] The Job Plan describes the required course of action by pre-determining the maintenance job procedure.

[30] Standard operating procedures are explicitly formulated, have a normative character and are also different from organizational routines (Cohen and Bacdayan 1994).

Cohen and Bacdayan (1994) define organizational routines[31] as patterned sequences of learned behaviour that involve multiple actors linked by relations of communication and/or authority, and explain that the actors involved may have heterogeneous objectives, knowledge, capabilities, level of competence, or even worldviews. Thus, organizational routines not only achieve a certain degree of control (Cohen and Bacdayan 1994), but also mediate between potentially conflicting interests (Nelson and Winter 1982; Grant and Baden-Fuller 2000) very often through knowledge integration and recombination, and through experimentation. However, in doing so, they are not likely to cause radical and fundamental organizational innovation (Hedlung 1994; Huang and Newell 2003; Fong 2003). The present research focuses mainly on preventive and reactive maintenance work, whose actors are mainly at the management levels of the case organization. Moreover, the thesis is concerned with how knowledge creation processes result in the reinforcement of these two fundamentally different organizational routines.

Organizational routines constitute a fundamental part of the organizational memory, since they are accumulated stocks of know-how (Nelson and Winter 1982) in the form of procedural knowledge (Cohen and Bacdayan 1994). In addition, they are practical (Nonaka et al. 2001a) and can be viewed as an organization's capacity to act (Stehr 1992) or as a possibility for action (Hargadon and Fanelli 2002). This capacity, which depends on local conditions and contexts, may remain unused or dormant, and when used it is also difficult to determine the ways and the circumstances in which it may find application (Stehr 1992).

Literature concerned with organizational routines highlights the issues of routine replicability within the same organization and routine imitation from one context to another (Nelson and Winter 1982), since the latter appears to be a factor in shaping differences amongst firms (Nelson 1991) and concurrently a factor for "institutional isomorphism" (DiMaggio and Powell 1983). Szulanski (2000) points out the importance of mechanisms through which routines are made common across a group of related organizations. Moreover, Levitt and March (1988) argue that socialization, education, imitation, problem-solving, and personnel movements are basic ways for the transmission and improvement of organizational routines.

However, and especially when organizational routines are applied in inappropriate situations or contexts (Cohen and Bacdayan 1994; Von Krogh et al. 2000a), they can also become "core rigidities" (Leonard-Barton 1992) and "defensive routines" (Argyris and Schoen 1996; Argyris

[31] Nelson and Winter (1982) define organizational routines as a model of repetitive organizational and individual activity.

1999), and can discourage employees to hide their insights and improvisations (Brown and Duguid 2000).

Although organizational routines are considered an important unit of analysis in organization studies (Levinthal 2000), their understanding is rather difficult, since their multi-actor nature can obstruct observations. In addition, they are often interwoven with experiential learning and influenced by history, and therefore they may preserve old and often out-dated technology artefacts. They may also be partially inarticulate (Cohen and Bacdayan 1994).

Besides organizational routines, Nonaka's framework views organizational culture as an additional routine knowledge asset. In general, culture started to be appreciated as a knowledge asset quite recently (Barney 1986; Boisot 1998). Schein (1983), adopting an integrative perspective[32] (Meyerson and Martin 1987; Martin 1992), which assumes that a culture is characterized by consistency, organization-wide consensus, and clarity, defines organizational culture as "the pattern of basic assumptions that the group has invented, discovered or developed to cope with its problems of external adaptation and internal integration, and that worked well enough to be considered valid, and therefore to be taught to new members as the correct way to perceive, think and feel the relation to those problems" (Schein 1983: 14). Culture is learned and is a collective phenomenon, which involves symbols, heroes, rituals, and values (Pettigrew 1979; Hofstede 1991). All knowledge assets are first and foremost cultural and only then technological (Boisot 1998) and this provides an explanation for the moderating role of culture (Nonaka et al. 2001a) during the use or application of other knowledge assets, which can even prevent organizational adaptations (Boisot 1998). Therefore, the creation and transmission of cultural knowledge assets is integrated with technological practice and practical knowledge (Boisot 1998). Other examples indicate that culture is often a barrier to knowledge management processes (Hayduk 1998).

This thesis assumes that the case organization, which provides mainly professional maintenance engineering services (Carlsen et al. 2004) has developed an engineering culture (Schein 1996), the fundamental assumptions of which are presented in Figure 2.6. Moreover, the research attempts to link the creation and reinforcement of this engineering culture to broader knowledge creation processes by explaining how existing culture embeds, articulates and reinforces the development of either a preventive or a reactive maintenance culture.

[32] The differentiation perspective (Smircich 1983; Van Maanen 1991; Rosen 1991; Trice and Beyer 1992) accepts the existence of subcultures. The fragmentation perspective (Weick 1990; Feldman 1991) views ambiguity as an inevitable and pervasive aspect of contemporary life.

Schein's (1985) framework is an appropriate framework for the examination and interpretation of this aspect of the role of cultural knowledge assets in processes of knowledge creation, since it can provide insights into how newly created knowledge integrates with and transforms the organizational routines. This framework examines a number of cultural dimensions, such as the organization's relationship to its environment, the existence of norms for behaviour within the organization, the nature of human activities and relationships, time urgency and the level of group diversity and homogeneity. Schein (1985) argues about the significance of culture embedding, and culture articulation and reinforcement mechanisms in the shaping of organizational culture. The existence of measures and controls, criteria for scarce resource allocation, role modelling, teaching and coaching and criteria for promotions, rewards and status are important culture embedding mechanisms. In addition, culture articulation and reinforcement mechanisms emphasize aspects such as organization design and structure, the existence of organization systems, procedures, rites and rituals, stories and myths, formal statements of organizational philosophy and values and more tangible issues such as the design of physical space. Several of the cultural dimensions and mechanisms proposed by Schein (1985) are also present in Alvesson's (1995) symbolic interpretative analysis of the organizational culture within a knowledge intensive firm.

Figure 2.6	**Assumptions of the Engineering Culture**

- Proactive optimism that engineers they can and should master nature.
- Engineers are stimulated by puzzles and problems and prefer "people free" solutions.
- The ideal world is one of elegant machines and processes working in perfect precision and harmony.
- Engineers overdesign for safety
- Engineers prefer linear, simple cause-and effect, quantitative thinking.

Adopted from Schein (1996: 14)

However, the use of Schein's (1985) framework for the delineation of cultural mechanisms within the knowledge creation process does not mean the adoption of its integrationist perspective, since a symbolic interpretation of the suggested mechanisms can allow for a cultural analysis illustrative of various perspectives, when for example, different subcultures are present (Robertson 1999). This point is important since, as indicated previously within the case organization the research identifies two fundamentally different subcultures, a preventive and a reactive maintenance subculture.

Furthermore, Schein (1985) focuses on the role of the corporate founder and provides case studies that describe both the successful and less successful conversions of explicit knowledge in the form of formal policies (systemic knowledge assets) into the cultural knowledge assets.

However, the use of Schein's framework (1985) is not limited in this thesis to the role of the founder or the leader for the shaping of cultural knowledge assets, but seeks to identify how other important roles of individuals or groups, as described by the knowledge activism framework (Von Krogh et al. 1997), use these culture embedding, articulation and reinforcement mechanisms.

Finally, besides organizational cultures, national cultures may have an impact on knowledge management processes (Hofstede 1991), and this may be of interest to the present research since the case organization is based in Greece. The Greek national culture is characterized by high uncertainty avoidance, whilst it appreciates collectivism and opportunities for earnings, recognition, advancement and challenges (Hofstede 1991).

Summarizing, the selected by this thesis knowledge assets, which are created and utilized within the case maintenance organization, and are shown in Figure 2.7, can facilitate an explanation about the continuity of the knowledge creation process. Hence, at the beginning of the SECI process, people within the case organization acquire maintenance skills and know-how, which at the externalization stage are used for the creation of maintenance repair concepts. These repair concepts are synthesized into more complicated sets of explicit knowledge, the Job Plans, which describe in detail the maintenance job to be executed. At the last stage of the knowledge creation process the actual performance of the maintenance job results in the development of technical know-how and preventive and reactive maintenance routines and culture.

Figure 2.7	**Four Categories of Knowledge Assets**
Experiential Knowledge Assets	**Conceptual Knowledge Assets**
Tacit knowledge shared through common experiences • Skills and know-how of individuals • Care, trust, commitment • Improvisation	Explicit knowledge articulated though images, symbols, and language • Maintenance Repair Concepts
Routine Knowledge Assets	**Systemic Knowledge Assets**
Tacit knowledge routinized and embedded in actions and practices • Know-how in daily operations • Preventive and reactive maintenance routines • Preventive and reactive maintenance culture	Systemized and packaged explicit knowledge • Maintenance Job Plans • Maintenance Databases • Maintenance Reports

Based on Nonaka et al. (2000a)

2.11 Developing and sharing knowledge assets

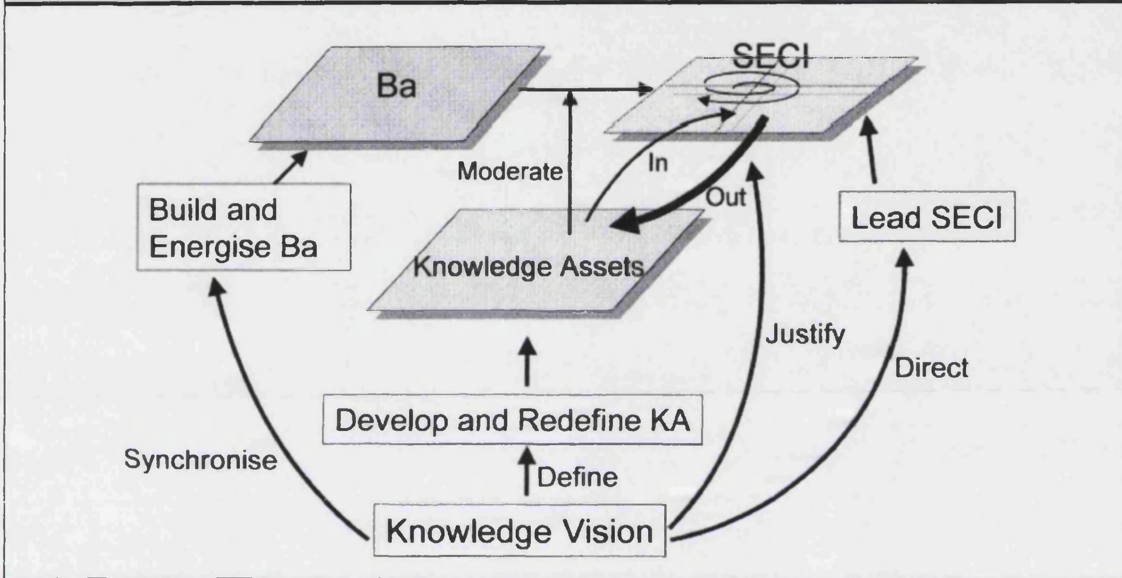
The issue of the development and the management of knowledge assets occupies an important role within the literature on knowledge processes (O'Dell and Grayson 1998; Teece 2001; Nonaka et al. 2001a). The facilitation of this dynamic process should be a responsibility of top management (Nonaka et al. 2001a) and requires not only the search and the assembly of knowledge (Murray 2001), but also the consideration of various organizational and social issues. Such issues include the existence of a knowledge vision and an innovative culture or, especially in industrial contexts as in the case organization, the existence of cost and demand logic, patents and compatibility standards, and of technological opportunities and political influences (Teece 2001).

Proposed strategies for the management of knowledge assets suggest either the development of difficult to imitate knowledge assets that are built in-house, mainly through knowledge creation processes, or their internal and external transfer (Teece 2001; Un and Cuervo-Cazurra 2004). Strategies for the in-house building of knowledge assets, which are a concern of the present thesis, require the redefinition of the organization on the basis of the knowledge it owns, rather than by using existing definitions such as technologies, products and markets (Nonaka et al. 2001a), which often tend to neglect the tacit nature of knowledge. Participants in the knowledge creation process have to understand the knowledge assets that are available, and the kind of knowledge they are lacking (Nonaka et al. 2001a). The mapping of existing knowledge assets facilitates the building, maintenance and utilization of knowledge assets. However, since these are dynamic, and new knowledge assets can be created from existing knowledge assets (Nonaka et al. 2001a), communication and accessibility issues are equally important (O'Dell and Grayson 1998) to the issue of knowledge assets ownership (Leadbeater 2001). Thus, for example, it is often difficult for large organizations to know exactly what they know, while in cases of internal transfer of routine knowledge assets in the form of best practices, the lack of a relationship between the source of knowledge and the potential recipient prevents its effective utilization (O'Dell and Grayson 1998). In such cases, the role of individuals is important since they provide direction for the creation and utilization of required knowledge assets (Nonaka et al. 2001a). In relation to the subject of this section, this thesis attempts to draw insights on how participants from various management levels of the case organization contribute, consciously or unconsciously, to the development and management of knowledge assets within the knowledge creation process.

2.12 About the management of the knowledge creation process

Having described the three elements that comprise the knowledge creation process, namely the SECI process, Ba and knowledge assets, and their interrelationships, which are presented in Figure 2.8, this section addresses two important aspects concerning the management of this process. The first issue concerns an appropriate management style for a knowledge creating organization, while the second relates to the infrastructure that supports knowledge creation processes.

Figure. 2.8 Development of the Knowledge Creation Process According to Nonaka



Adopted from Nonaka et al. (2000a: 23)

Similar to communities of practice, which are emergent, and therefore need detection and support instead of "artificial" interventions (Brown and Duguid 1991), the knowledge creation process cannot be managed in the traditional sense of "management", which centres on controlling information flows (Von Krogh et al. 2000a; Alvesson and Karreman 2001; Klint and Verhoef 2002) and is usually achieved through traditional top-down leadership. Rather, Nonaka proposes a "middle-up-down" style of management (Nonaka 1988b; Nonaka 1994), arguing that middle managers, who are at the intersection of the vertical and horizontal flows of information in a company should, promote the active and dynamic creation of knowledge (Nonaka 1991; Nonaka 1994). Ideally, in middle-up-down management, middle managers are the actual knowledge producers, since they both create and participate in Ba, whilst they interact actively with others. In addition, middle managers lead self-organizing teams who synthesize the tacit knowledge of both frontline employees and top management. Despite the lack of overall control of the organization in the middle-up-down management model (Nonaka 1994), a joint top and middle management leadership could orient chaotic situations toward purposeful knowledge creation (Hedlung 1994) through the provision of a knowledge vision (Nonaka 1994).

Having said this, the current research does not intend to examine middle-up-down management within the case organization, since this adopts a more traditional a top-down style of management. Rather, it intends to explain the role of the middle management within the existing knowledge creation process. This is pursued by delineating how this employee group performs the roles of knowledge activism (Von Krogh et al. 1997).

Academic research has showed that there is a link between the organizational structure and the quality of created knowledge (Birkenshaw et al. 2002). Nonaka (1994) argues that middle-up-management is more efficient with the support of an appropriate infrastructure, which is provided by the "hypertext organization"[33]. According to internal or external conditions such an organization is able to switch between the acquisition, generation, exploitation and accumulation of knowledge combining the efficiency and stability of a hierarchical bureaucratic organization with the dynamism of the flat, cross-functional, task-force organization. The hypertext organization comprises of three layers (bases), which find their equivalents to the professional maintenance service organization in the case company. Thus, without arguing that the case maintenance organization is necessarily a hypertext organization, its formal hierarchy is equivalent to the business base of the hypertext organization, that is, the formal structure that carries out routine operations. The project base that includes the knowledge creating teams is equivalent to the maintenance teams from various departments of the case organization. These collaborate in affecting equipment repairs. Finally, the knowledge base of the hypertext organization that embraces existing tacit and explicit knowledge corresponds to maintenance skills, know-how and other knowledge necessary for all maintenance works. The hypertext organization has an ability to switch between these three layers (Nonaka 1994) and is ready to take advantage of environmental opportunities by combining and recombining existing schemes, arrangements and resources, similar to Ciborra's (1996b) platform organization.

It is not only the hypertext organization, but also the theory of neo-industrial organizing (Ekstedt et al. 1999), which deals with work between permanent and temporary organizations and adopts an organizational behaviour approach, that suggests knowledge creation processes move between a business and a project layer. According to the latter theory, the issues of how temporary project-based organizations, like the maintenance project teams of the case organization, utilize existing knowledge, and how newly generated knowledge becomes

[33] Lessem (1998) extending Nonaka's work proposed the unification of middle-up-management with the concept of the hypertext organization within the concept of global businessphere.

internalized, require further empirical support (Ekstedt et al. 1999; Asheim 2002). The present thesis is not explicitly concerned with these two issues only, since its objective is broader. However, since the inquiry considers it prudent to include rich information about both the business and the project layers of the case maintenance organization, due to their importance for the knowledge creation processes, conclusions can be drawn in relation to the hypertext organization and the theory of neo-industrial organizing (Ekstedt et al. 1999).

2.13 The role of the knowledge vision within knowledge creation processes

The continuous and dynamic creation of knowledge requires a knowledge vision to synchronize and drive the entire organization, which should be provided by top management (Nonaka et al. 2001a; Nonaka and Toyama 2002). Such a "vision should define the "field" or "domain" that gives corporate members a mental map of the world they live in and provides a general direction as to what kind of knowledge they ought to seek and create" (Nonaka and Takeuchi 1995: 227). Knowledge vision should form the basis of knowledge and business strategy (Zack 1999a) by explicating the organizational intention or the purpose of the company's existence (Garratt 2001a). A knowledge vision facilitates overcoming the frequent problem of reliance on successful past experiences (Von Krogh et al. 2000a) and defines the value system that evaluates, justifies and determines the quality of the knowledge that is created. In general, the literature agrees that a vision comprises two components, one that concerns foresight about the future of the organization and another one that refers to the present state (Peters 1987; Von Krogh et al. 2000a). Some have argued that in practice, a company's knowledge vision may take the form of a mission statement, a set of corporate values, a document about management philosophy, or a plan similar to a strategic outline (Von Krogh et al. 2000a), whilst others argue that a vision should not be achievable in the short or medium term (Garratt 2001a; 2001b).

Furthermore, the knowledge vision not only specifies what knowledge organizational members need to seek and create, but it also defines the criteria according to which new knowledge should be assessed (Von Krogh et al. 2000a). A good knowledge vision should be committed to a direction, generate new organizational knowledge, adopt a specific style enabling the self-definition of the organization, focus on restructuring the current knowledge and task system, communicate externally the organizational values, and contribute to the acquisition and maintenance of competitiveness (Von Krogh et al. 2000a). The present empirical research attempts to explain the quality of the knowledge vision that directs knowledge creation within the case organization using such criteria as these.

A commitment to a knowledge vision, which also requires consistent and frequent communication, avoids employee fragmentation, since it forms the basis for interpreting both everyday working life and the organizational environment. However, the communicated vision should be equivocal in that, while it should direct towards a future state, it should not dictate how this situation could be achieved (Nonaka and Takeuchi 1995). This might not only foster the creation of new knowledge, but it would also enable the generation of new ideas about the application of existing or dormant knowledge (Von Krogh et al. 2000a; McAdam 2004).

2.14 Summary

The purpose of this chapter was not merely to present the framework that is used in the pursuit of the research objectives, but also to show how it will explain the interrelations of knowledge creation processes with their context and their content and the influence of individual and group actions and interactions upon them. An attempt has also been made to position the research framework within the wider academic literature by pointing out debates, issues of interest and research gaps. This was attempted and covered in each section by pursuing a range of themes.

The chapter started with a presentation of the adopted definition of knowledge, a discussion on alternative perspectives and typologies on knowledge, and the presentation of two perspectives on knowledge, a structural and a processual one (Newell et al. 2002). Then, it was argued that Nonaka's framework can address the phenomenon of knowledge creation better than other structuralist frameworks (Spender 1996a, 1998; Blackler 1995). The current research uses the Unified Model of Dynamic Knowledge Creation, the most recent and integrated version of Nonaka's framework, which addresses not only how knowledge creation occurs, but also deals with the context and the content of the process. The chapter continues with a presentation and a critical discussion of the three constituting elements of the research framework starting with the SECI process. The following sections explained how the context for knowledge creation processes is approached in this investigation. So, after a presentation of a taxonomy of Ba, the chapter describes how the thesis is concerned with the context's shaping through individual and group roles, which are interpreted through the knowledge activism framework (Von Krogh et al. 1997). The research also recognizes the contribution of media, and in particular of ICT for shaping the knowledge-creating context, while not intending to examine in-depth their role within the knowledge creation process. Rather, the thesis is concerned with the organizational conditions of autonomy, creative chaos, information redundancy, requisite variety and care, trust and commitment that contribute to the building and energizing of this context, since they influence its social interactions (Chua 2002). Then, the chapter explains that the investigation approaches the issue of the content of knowledge creation processes though the concept of knowledge assets (Nonaka et al. 2001a) and explicates how these fit in the broader research. Amongst other things, the thesis is concerned with the conscious or unconscious development and management of knowledge assets within the case organization. In addition, the issue of an appropriate management style for processes of knowledge creation, the contribution of a suitable infrastructure for the support of this social process and the role of the knowledge vision are all introduced.

Figure 2.9 summarizes how the present research links the knowledge creation process with its context and its content within the case organization.

Figure 2.9	**Linking the Knowledge Creation Process with its Context and its Content**				
The knowledge creation process	**Horizontally from left to right: Progression of the knowledge creation process**				
	Phase A	**Phase B**	**Phase C**	**Phase D**	
The SECI Process	**Socialization**	**Externalization**	**Combination**	**Internalization**	**Vertically: Interconnection of the knowledge creation process with its context and its content within each phase of the process**
	Maintenance skill acquisition process	Fault identification process	Planning and scheduling process	Execution of maintenance works	
The process context					
Concept of Ba	**Originating Ba**	**Dialoguing Ba**	**Systemizing Ba**	**Exercising Ba**	
	Face-to-face individual interactions	Face-to-face collective interactions	Virtual collective interactions	Virtual individual interactions	
The process content					
Knowledge Assets	**Experiential Knowledge Assets**	**Conceptual Knowledge Assets**	**Systemic Knowledge Assets**	**Routine Knowledge Assets**	
	• Skills and know-how of individuals • Care, trust, commitment • Improvisation	• Maintenance Repair Concepts	• Maintenance Job Plans • Maintenance Databases • Maintenance Reports	• Know-how in daily operations • Preventive and reactive maintenance routines • Preventive and reactive maintenance culture	

In conclusion, the chapter not only establishes the importance of the Unified Model of Dynamic Knowledge Creation as a lens through which the research makes sense of knowledge creation processes, but also points out that little empirical research has been conducted in relation to its three constituting elements (Lessem and Palsule 1999). The review of the literature revealed the lack of holistic empirical research that combines the knowledge creation process with its content and its context, since the SECI process, Ba, and knowledge assets had till now been considered separately. Moreover, the chapter explains the need for a theoretical triangulation (Denzin 1978), which covers some weaknesses of Nonaka's framework, primarily through the use of knowledge activism framework (Von Krogh et al. 1997) for the delineation of social interactions, and a number of other supportive concepts and frameworks for the explanation of the role of intangible knowledge assets. Therefore, having established the need for a more integrated approach to knowledge creation processes and having presented the combined research framework, we now turn, in Chapter 3, to a consideration of the philosophical and methodological assumptions that underpin the present research and how such an investigation should proceed.

3

Theoretical Assumptions and the Investigative Approach

3.1 Introduction

This chapter argues about the philosophical and methodological assumptions that underpin the investigation, and describes in detail aspects of the research design and analysis. This is attempted by pursuing a number of themes.

Since investigators in every kind of research should take into consideration the necessity to align the research objectives, the theoretical foundations and the adopted methods of the research (Robey 1996), the first theme points out some key aspects of the investigative focus that influence both the assumptions and the approach adopted. Thus, the first theme explicates the definition of the term "process" (Van de Ven 1992) adopted here and argues how a knowledge creation process should be investigated. The second theme explains the suitability of the philosophical and methodological assumptions of the interpretative approach (Walsham 1993; 1995b; Chua 1986) for the investigation of knowledge creation processes, in contrast to positivist and critical approaches (Orlikowski and Baroudi 1991). Then, having established the need for an interpretative epistemological approach, the third theme argues for the adoption of a case research strategy (Benbasat et al. 1987). The remaining themes in this chapter deal with important issues of the research design. Thus, theme four presents reasons for the selection of the case organization. Theme five describes how the researcher negotiated and obtained access to the research site, while a sixth theme includes some reflections about the researcher's skills and his role in relation to the research design. Theme seven, describes the datasets that were collected and used in the research. Theme eight focuses on the establishment of communication channels and rapport with case organization actors, and details data collection procedures. Theme nine describes the adopted data analysis strategy, while theme ten explicates the unit of analysis of the research. Finally, the chapter ends with reflections on the quality of the research conclusions.

3.2 A process view on knowledge creation

The epistemological and methodological assumptions underlying my empirical research, in other words the criteria by which valid knowledge about the phenomena under investigation may be constructed and evaluated, and the appropriate research methods and techniques for gathering valid empirical evidence (Orlikowski and Baroudi 1991) are strictly interconnected not only with its investigative focus, but also with the research design (Robey 1996). As already explained, the investigative focus concerns the development of a deeper understanding of the dynamics of knowledge creation processes. Thus, it is prudent first to make explicit the meaning of the term process as used in this research, and to examine how processes of knowledge creation can be investigated. Such an approach can determine not only the underlying research assumptions, but also the research strategy and design.

The term "process" has been defined in three ways in both the strategy literature and also in the wider literature on organizational processes (Van de Ven and Huber 1990; Van de Ven 1992). The first definition offers a static view of process, similar to a variance theory (Mohr 1982), since it associates the inputs with the outputs by stating that process is the "logic that explains a casual relationship between independent and dependent variables" (Van de Ven 1992: 170). However, such a definition allows for the development of restrictive and unrealistic assumptions about the order and sequence in which events unfold in organizations (Van de Ven and Huber 1990) and obstructs direct observation (Van de Ven 1992). The second definition explains that a process is "a category of concepts or variables that refers to actions of individuals and organizations" (Van de Ven 1992: 170). This definition enables the examination of variables, such as information flows, over time and therefore can answer the question whether knowledge creation has occurred through the transformation of information. However, it cannot give an account for how this knowledge creation has taken place. This weakness can be overcome with the adoption of a third definition, which views of processes as "a sequence of events that describes how things change over time or that represents an underlying pattern of cognitive transitions by an entity in dealing with an issue" (Van de Ven 1992: 170). This definition takes a historical, developmental perspective, and implies that the nature, sequences and order of incidents, activities, and stages that unfold over an organization's existence (Van de Ven 1992) are important for the knowledge creation process and its outcome. The definition points out the importance of how an organization uses its capacity for action (Stehr 1992), its knowledge in other words. Thus, the latter process definition is adopted, since this perspective on knowledge creation process is in accordance with the investigative focus.

The different perspectives of the three process definitions (Van de Ven 1992) indicate that research that attempts to embrace the third one is more likely to provide valuable insights about the process itself. The deeper reflection on this assertion leads us, paraphrasing McDonagh (1999: 79), to the argument that what presents itself as research on knowledge creation is in fact "aprocessual", since it does not pay attention to the process dimension. One potential explanation for this could be the fact that the knowledge creation process is frequently reduced to a typology of knowledge. For example, on the one hand, Spender (1996a) argues for a pluralist epistemology of knowledge and for the creation of a theory of the firm as a system of knowledge types and processes. He identifies four different situated (Suchman 1987) and embedded (Brown and Duguid 1991; Lave and Wegner 1992) types of organizational knowledge that interact dynamically at both the individual and the organizational level. However his framework is unable to explain how these types of knowledge interact and thus how an organization favours knowledge creation and application processes (Spender 1996b: 51). On the other hand, Blackler (1993) accepts that knowledge[34] is socially constructed (Berger and Luckmann 1966) and situated (Suchman 1987), meaning that he recognises the importance of incidents and activities for knowledge creation. However, while his initial intention was to focus on processes through which new knowledge may be generated, and for this reason he adopted Engestrom's (1991) argument that socially-distributed activity systems are the most appropriate unit of analysis for studying the process of knowing, the practical value of his framework (Blackler 1995; Blackler et al. 1998) is mainly the association of different types of organizations with dominant types of knowledge. Thus, while both frameworks (Spender 1996a; 1996b; Blackler 1995; Blackler et al. 1998) accept that knowledge creation processes are context dependent (Pettigrew 1985; 1990; 1992) they embrace the second definition of process (Van de Ven 1992), and as a result neglect the developmental nature and the characteristics of these processes.

Notwithstanding, when it comes to processes of knowledge creation, the clearest compliance to the third process definition is achieved by Nonaka's Model of Dynamic Knowledge Creation (Nonaka et al. 2001a), and this qualifies it both as a driver of data collection and as a conceptual lens for analysis (Walsham 1995b). In addition, this model, like a process theory, accepts that

[34] For Blackler (1993) knowledge is also tacit (Polanyi 1966), enacted (Weick 1979), distributed (Hutchins 1983), material, as well as mental and social (Latour 1987), resilient, but provisional and developing (Unger 1987), public and rhetorical (Vattimo 1988), which is acquired through participation within communities of practice (Lave and Wegner 1991).

reality is constructed as a continuous and patterned sequence of events (Abbott 1990; Pettigrew 1992; Van de Ven and Huber 1990; Shaw and Jarvenpaa 1997) and explains how and why (Van de Ven 1992; Van de Ven and Poole 1995) the process of knowledge creation unfolds over time and the entity of organizational knowledge develops.

Moreover, knowledge creation processes are also change processes, due to the fact that new knowledge has mainly an incrementally transformative character (Nonaka 1994; Hedlung 1994). Hence, using the taxonomy for the identification of change process theories (Van de Ven and Poole 1995), Nonaka's framework can be categorized as an evolutionary process theory. The usefulness of this taxonomy lies in the fact that it provides different accounts of the sequences of events that unfold to explain the process of change in an organizational entity (Van de Ven and Poole 1995). Consequently, the taxonomy explains that Nonaka's framework accepts that knowledge creation events progress with a recurrent, cumulative, and probabilistic sequence of variation, selection, and retention of organizational entities.

Having explained the adopted definition of the term "process" and having argued that Nonaka's framework fits this definition, and therefore appears suitable for research in knowledge creation processes, the next logical step is to reflect on how such processes could be observed and investigated. This issue acquires even greater importance considering the fact that the adopted process definition does not separate a process, from either its content, or its context.

Indications from research in the fields of strategy processes[35] (Van de Ven and Huber 1990; Chakravarthy and Doz 1992), organizational and business processes[36] (Monge 1990; Pentland 1995; Malone et al. 1999; Dooley and Van de Ven 1999; Davenport et al. 1996), software development processes (Elam et al. 1991) and knowledge creation processes (Eriksson et al. 2000), advocate that their study requires thorough observation and analysis. However, when such research also involves process models, it has the potential to address a wide range of questions (Shaw and Jarvenpaa 1997), and even organizational-level issues (Orlikowski 1993).

[35] Harrison (1995) argues that strategy processes are a funnel type of business processes.

[36] The thesis differentiates business processes (Davenport and Short 1990; Hammer 1990; Davenport 1993; 1995; 1996; Harrison 1995) from knowledge processes, despite their common elements, such as the dependence on information and knowledge flows (Davenport 1993; Meyer and Zack 1996) and their situated character (Hammer and Champy 1993). Hence, the first ones tend to adopt the second definition on term "process" (Van de Ven 1992) and they put extreme emphasis on the use of explicit knowledge, since even if a work requires the utilization of tacit knowledge, this has to be done within a framework set up by the explicit business process. This approach neglects calls to focus on how work is done (Davenport 1993; Earl 1994b). Skyrme (2001) argues that knowledge processes are more fluid and subject to change than business processes. The adoption of the third process definition by business processes would require the development of an organizational culture, which often proves to be a time consuming process (Zairi 1997).

In addition, process research should point out not only the sequences of (knowledge creating) events and their underlying logic, but also the patterns in these sequences. It should also address why these patterns exist and what influences them. Moreover, process research should be in a position to establish how sequences of events influence outcomes (Abbott 1990; Pettigrew 1990; Van de Ven and Huber 1990; McDonagh 1999).

More specifically, for the identification of guidelines for research concerning knowledge creation processes, the adaptation of Pettigrew's (1992) principles for research in strategy processes, which argue for the development of a wider understanding of the role of context in the historical development of processes, could provide useful insights. Such an adaptation could contribute to the clarification of the "distinctiveness and additiveness" (Pettigrew 1992) of knowledge creation research by defining aspects of the process analysis. Thus, according to the first principle, knowledge creation processes are embedded in complex organizational contexts and can only be studied as such. Second, process research should reveal temporal interconnectedness in order to identify process continuity and to facilitate an understanding about the sequence and flow of events. Third, process research should not neglect that context and action are inseparably intertwined with the process itself. Fourth, it is important that research on knowledge creation should search for holistic rather than linear explanations. Finally, process analysis should be linked to the location and the explanation of outcomes, since this could provide a focal point for the investigation and could encourage the exploration of how and why contextual and processual variations may shape observed outcomes (Pettigrew 1992; Robey and Sahay 1996).

3.3 Explicating the need for the adoption of a heretical[37] (interpretative) approach

The investigative focus of the research, as defined by the research questions, along with the adopted process definition and the guidelines for conducting research associated with knowledge creation processes dictate the assumptions, both philosophical and methodological, that underpin the research. Thus, amongst the three widely accepted (Orlikowski and Baroudi 1991; Walsham 1995a; Myers 1997) philosophies in information systems research, meaning

[37] Many centuries before the term "heresy" acquired a definition as "belief or practice contrary to orthodox doctrine" (The Concise Oxford Dictionary) and its religious connotations, mainly with the spreading of Christianity, Plato utilized the Greek verb "αίρω" (hairo: raise) in his academy simply to describe someone's act of standing up and expressing his/her interpretation on a topic during discussions or symposia.

positivist, interpretative and critical approaches[38] (Chua 1986), interpretivism, and especially the kind that it is rooted in phenomenology[39] (Boland 1979; 1985; Schwandt 2000; Gubrium and Hostein 2000), appears to be aligned with these requirements (Galliers 1997), due to its underlying set of beliefs that "delineate a way of seeing and researching the world" (Rosen 1991b). These beliefs, which are nothing other than assumptions constituting the philosophical stances that researchers adopt towards the world and their work (Chua 1986), concern the phenomenon or the "object" of study, the notion of knowledge and the relationship between knowledge and the empirical world.

Hence, first, interpretivism asserts that reality, as well as our knowledge thereof, is a social product and hence incapable of being understood independent of the social actors that construct and make sense of that reality (Orlikowski and Baroudi 1991). Hence, the underlying ontological assumptions about physical and social reality of the interpretative research philosophy emphasize the importance of subjective meanings and social-political, as well as symbolic action in the processes through which humans construct and reconstruct their reality (Orlikowski and Baroudi 1991). The social world is produced and reinforced by humans through their action and interaction. Unlike the premises of the positivist perspective (Silverman 1998; Goles and Hirschheim 2000), where researchers are presumed to "discover" an objective social reality, interpretative researchers (Gopal and Prasad 2000; Myers 1998; Trauth and Jessup 2000) believe that social reality can only be interpreted and its regularities are not attributed to functional needs of the social system, but to the shared norms and interests that bind humans together. Interpretative researchers adopting the principles of phenomenology start with the assumption that access to reality is only through social constructions such as language, consciousness and shared meanings, while the development of an understanding is a dialectic process that involves these elements (Boland 1979; 1985). Consequently, the assumed dynamic nature of the social reality of knowledge creation, which "occurs rather than exists" (Pettigrew 1992) suggests the rejection of positivist methods, since they tend to neglect not only the nature, but also the sequence and order of events of such processes (Abbott 1990).

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[38] Mingers (2001b) adopts a similar distinction with the exception that he replaces the critical research epistemology with a wider one, the interventional epistemology.

[39] Interpretivism is not a single approach and its different approaches are rooted in different philosophical basis. There are at least four different strands of interpretative thought (Mingers 1984): phenomenology, ethnomethodology, the philosophy of language, and hermeneutics. Another division (Lee 1991) categorizes interpretative research into phenomenological sociology, hermeneutics (Davis et al. 1992; Lee 1994; Butler 1998) and ethnography. Moreover, Klein and Myers (1999) recognize that there are many other forms of interpretivism that are not necessarily hermeneutic, such as postmodernism or deconstructionism. Phenomenology and hermeneutics treat the study of information systems as a process of interpretation of the significance and potential meaning they hold, from the perspectives of both the designer and the user (Walsham 1993).

Second, the interpretative philosophy adopts the epistemological belief that "social process is not captured in hypothetical deductions, covariances, and degrees of freedom. Instead, understanding social process involves getting inside the world of those generating it" (Rosen 1991b: 8). Therefore, intensive, field studies are considered as appropriate to generating interpretative knowledge, as these examine humans within their social settings (Orlikowski and Baroudi 1991). Indeed, one of the most influential studies in the field of information systems research depicts interpretivism as an appropriate approach for research on change processes (Walsham 1993). Longitudinal studies are particularly favoured when it comes to process research.

Third, the assumption of interpretative research philosophy for the relationship between theory and practice accepts that the researcher can never assume a value-neutral stance, and is always implicated in the phenomena being studied (cf., Checkland 1981). Researchers' prior assumptions, beliefs, values and interests always intervene to shape their investigations (Orlikowski and Baroudi 1991). In contrast to interpretative studies, the premises of positivist research are the existence of a priori fixed relationships within phenomena, which are typically investigated with structured instrumentation (Orlikowski and Baroudi 1991), coupled with the assumption that reality is objectively given and can be described by measurable properties that are independent of the researcher and his/her instruments. Thus, and given that the complexity of the knowledge creation phenomenon does not enable the identification of a priori fixed relationships for the testing of theory, which often happens in positivist studies (Baroudi and Orlikowski 1989; Myers 1997), a positivist epistemology would seem to be inappropriate for the present research.

Thus, this research accepts, following interpretivism, that the reality of knowledge creation processes can neither be given objectively, nor be described by measurable properties that are independent of the researcher and his instruments. Therefore, attention should be drawn not only to the human actors in the research situation, but also to the users of the research methods and the research methods per se (Mingers 2001a), which are the instruments for provoking responses from the world. These responses depend on both the world and the instrument (Mingers 2001a). Consequently, an interpretative investigation such as the present one should address, inter alia, three sets of relationships: those between the researcher and the situation, those between research methods and the situation, and those between the researcher and the methodologies (Mingers 2001a). This is because each has inherent biases (Baskerville 1991).

The role of the researcher within the situation cannot assume a neutral stance. This and the relationship of the researcher with the methodology are described in detail later in this chapter.

Now, emphasis is given to the role of theory in this research, which is a key question for researchers in any tradition, regardless of philosophical stance. Eisenhardt (1989) discusses this issue in the context of organizational studies, and identifies three distinct uses of theory: as an initial guide to design and data collection (Walsham 1993); as part of an iterative process of data collection and analysis (Orlikowski 1993); and as a final product of the research (Orlikowski and Robey 1991). As indicated, the present research uses Nonaka's framework (Nonaka et al. 2001a) not only as a guide for data collection, but also as the primary lens through which collected data are interpreted. Hence, not only the research uses the prefixed theoretical framework as "a sensitising device to view the world in a certain way" (Klein and Myers 1999: 75), but also theory is used as a guide for the investigation and the collection of data. Such an approach is somehow different from the mainstream interpretative research, which often devises a framework out of the collected data (Walsham 1995b) rather than using a predefined framework to guide the research.

The selection of Nonaka's framework for interpretative research is not only dictated by its processual perspective (Van de Ven 1992) on knowledge creation, but also by its adopted definition of knowledge as "justified true belief", which categorizes it, using Burrell and Morgan's (1979) grid, to the interpretative sociological paradigm that assumes the social construction of reality (Berger and Luckmann 1966).

However, at this point, it should be acknowledged that the interpretative research philosophy has been subject to criticism for not examining thoroughly the conditions, which give rise to certain meanings and experiences, for silencing the provision of explanations of unintended consequences of action, for not addressing explicitly the structural conflicts within society and organizations, and for neglecting to explain historical change (Orlikowski and Baroudi 1991). Most of these concerns can be overcome with the adoption of a critical philosophical stance (Hirschheim and Klein 1994; Ngwenyama and Lee 1997; Doolin 1998), which aims to critique the status quo, through the exposure of what are believed to be deep-seated, structural contradictions within social systems, and thereby to transform these alienating and restrictive social conditions (Orlikowski and Baroudi 1991; Lyytinen 1985). Such a critical stance assumes that social reality is historically constituted and that the contradictions inherent in existing social forms lead to inequalities and conflicts, from which new social forms will emerge. In addition, critical researchers, with the aim of intervening in the situation, believe that they need to understand the language of the humans they are studying, an understanding that is temporally and spatially bound (Orlikowski and Baroudi 1991; Ngwenyama 1991). For example, according to the Scandinavian tradition in IS development the analyst (or researcher) plays the role of the emancipator or even the role of the social therapist (Hirschheim and Klein 1989, Kensing and

Munk-Madsen 1993). However, the basic difference of the present research with the critical epistemological approach lies in the fact that, despite the recognition of historical influences upon the development of the case organization, the researcher does not have the aim of changing the existing social reality.

3.4 Research strategy

Having explicated the need for the adoption of an interpretative stance, this section describes the research strategy. The investigation adopts a case research strategy that is well-suited for capturing practitioners' knowledge and the development of theories (Benbasat et al. 1987; Mintzberg 1979). Moreover, a case research strategy can follow either the positivist or the interpretivist tradition (Lee 1989; Galliers 1985; 1991; 1993; 1995; Cavaye 1996; Stake 2000). A widely accepted definition of the case research strategy describes it as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between the phenomenon and its context are not clearly evident; and in which multiple sources of evidence are used (Yin 1981; 1984). Such a strategy is also suitable for the adopted interpretative epistemological approach (Walsham 1993).

On the one hand, the literature lists a number of reasons for adopting of a case research strategy (Leonard-Barton 1990; Gable 1994; Darke et al. 1998). First, case research allows the investigator to study information systems and knowledge creation processes in a natural setting, to learn about the state of the art, and to generate theories from practice (Benbasat et al. 1987; Luthans and Davis 1982). Second, such a strategy allows answering "how" and "why" questions, thereby facilitating understanding of the nature and the complexity of various processes (Benbasat et al. 1987; Yin 1984; Eisenhardt 1989; Shanks 1997; Tsoukas 1989). Hence, an important advantage is the opportunity for the provision of a holistic view of processes (Gummesson 1991; Lincoln and Guba 2000). A case approach is also appropriate for researching areas in which few previous studies have been carried out and thus valuable new insights can be provided (Benbasat et al. 1987).

However, on the other hand, criticisms of case research cannot be neglected (Yin 1984; Gummesson 1991; Cavaye 1996). Generalizations cannot easily be made on the basis of case studies; they often lack internal validity, and there is no control over independent variables. Many consider case research inferior to methods that are based on random statistical samples of a large number of observations (Gummesson 1991). Moreover, while case studies can be used for hypotheses generation, these cannot be tested, since such research assists the development of an understanding of structures, processes and driving forces, but not cause and effect relationships.

However, the limitations of case research can largely be overcome through rigorous research design, data generation and analysis. As far as the present research is concerned, the adoption of a process-oriented case study (Miles and Huberman 1994) that will enable the capture of the organizational and social setting and some aspects of the process itself and its content, appears to be a suitable method for investigating the development and the dynamics of situated knowledge creation processes, since there is no need for manipulation or control of subjects or events. Such an approach would also answer calls to cater for context in information systems research (Avgerou 2001) and would be able to follow events over time at a previously inaccessible to scientific investigation site (Benbasat et al. 1987; Cavaye 1996). By studying the process of knowledge creation, this interpretative case study aspires to provide some generalizable observations (Walsham 1995b) that will assist conceptual development, draw specific implications (Walsham and Waema 1994) and provide insights that can be considered valuable (Orlikowski 1991).

The case research strategy adopted here is also quite distinct from several other research strategies that make use of the case method, and that may share common characteristics (Cavaye 1996). The main difference of the present research with field studies is that the researcher has not defined a priori relationships between phenomena (Walsham and Waema 1994; Myers 1994). Moreover, the present research does not aim at providing a description of a successful application or to illustrate a conceptual issue (Bonoma 1985), which is the purpose of case application descriptions. Rather, it aims to investigate in-depth knowledge creation processes and their relationships with their context and their content.

However, the investigation shares common characteristics with action research (Avison et al. 1999; Avison et al. 2001; Lau 1997; Baskerville and Pries-Heje 1999), such as the use of observation and participatory methods for data collection. Nevertheless, the present research is not based on its underlying principles (Checkland 1981; 1991; Wood-Harper 1985; Baskerville 1999) that seek to bridge the gap between theory and practice. One distinction is that the investigator does not have the intention of actively taking part in the resolution of any problems at the research site. Thus, there is lack of an action plan to set objectives, timescales and agree outcomes with organizational actors. Another distinction is the lack of an attempt to control any variables. Moreover, the research neither tests a particular methodology (e.g. SSM) nor a theoretical construct, with the aim of their further development, as would be the case of action research (Checkland 1981). Rather, it attempts to make sense (Weick 1988; 1993; 1995) of the collected data and it does so by adopting an ethnographic style of approach.

Having said that, ethnography (Harvey and Myers 1995; Myers and Young 1997; Myers 1999; Klein and Myers 1999) seeks to understand the meaning of phenomena that participants at a site assign. The ethnographer does not enter a site with pre-defined constructs and does not assume data to be factual. However, instead of interpreting data through the eyes of the participants (e.g. Suchman 1987), the present research interprets data utilizing a pre-existing conceptual framework, Nonaka's framework, while the researcher observes actions and interactions amongst the key players, and listens intently to what they have to say.

3.5 Selection of the research site

The present research focuses on a single site (Eisenhardt 1991): on "a revelatory case in a situation previously inaccessible to scientific investigation" (Benbasat et al. 1987), rather than multiple cases. Thus, the attractiveness of this case study lies in the opportunity to examine and provide insights and perspectives in relation to the knowledge creation process from a southern European (Greek) organization, the Athens oil refinery of Petrochem and its Maintenance Division, given different cultural characteristics to those exhibited in Anglo-Saxon or Asian organizations (Galliers 1995).

Moreover, the pioneer position of the case organization in its sector, since it is ranked among the six most productive and technologically advanced oil refineries in Europe, also makes the study of this case more intriguing. Having this in mind the researcher made an opportunistic selection of this particular site (Buchanan et al. 1988), fulfilling concurrently at least three case selection criteria for such a decision (Burgess 1984): (i) an increased degree of access, (ii) the familiarity of the investigator with the organizational setting, the language and the culture of Greek public industries, and (iii) the increased possibility for the researcher to participate in a series of ongoing activities.

However, the selected site also comprises an instrumental case (Stake 2000), since it is examined mainly for the provision of insights into the knowledge creation process. Thus, although the research's investigative focus may remove the interest from the case per se, the research is still looking at it thoroughly (Dyer and Wilkins 1991), scrutinizing its contexts, and examining its ordinary activities for all the above-mentioned reasons.

3.6 Negotiating and obtaining access

Access to the case organization and to data sources was not a straightforward procedure (Burgess 1984), since it was obtained by the instrumental contribution of the researcher's employer, a leading Greek industrial consultancy, which gave him the opportunity to enter in January 2000 during a Business Process Reengineering project in the Maintenance Division, prior to the corporate-wide implementation of an ERP system. The employer played the key role of informant and mediator, who approached gatekeepers (Burgess 1984; Gummesson 1991; Taylor and Bogdan 1998) in the case organization, requesting access on behalf of the investigator. Hence, the investigator did not enter the organization performing the traditional role of the academic researcher, but with the dual, but common, identity in information systems research (Gummesson 1991; Zuboff 1988), as a researcher and as a junior consultant, which dealt with both organizational and technical issues during the BPR project at the Maintenance Division. At this point it should be clarified that as a junior consultant the researcher did not have any influence on the decisions concerning the BPR project, which was unsuccessful, since it only produced a number of documents with recommendations for improvements and left the maintenance workflow activities unchanged. In addition, the interviews for this research were conducted after the end of this project.

Access to the case organization was feasible for a number of reasons. First, the strong academic background and teaching experience, of one of the founders of the researcher's employing company, made him eager to be of help for this doctoral study. In addition, the gatekeepers of the case organization, namely the Technical Director of Petrochem, the Manager of the Maintenance Division and the Department Heads provided access, based on long-standing and trusting relationships with the consultancy for more than a decade. Third, the case organization had a long–established tradition of providing data to postgraduate students. Indeed the investigator had the opportunity to verify this, since during the data collection period the Head of the Procurement Department proudly showed him his PhD in Management obtained with data provided by the company. Moreover, during the same period another postgraduate student, the son of a low-level employee, was also collecting data for his MSc dissertation at Cranfield University.

The researcher did not sign any binding legal document with the organization, since on the one hand top management considered the credibility of the mediating consultancy adequate, and on the other, their previous experience had showed that academic research conducted ethically did not constitute any particular risk (Taylor and Bogdan 1998). However, when discussions tuned to data collection, it was explicitly stated by top management that the researcher had an obligation to respect the organization's wish for confidentiality (Christians 2000). In particular, the researcher was advised not to disclose financially sensitive information. This provides some answer for those who argue that organizational secrecy could threaten research (Yin 1984; Editorial 1994).

Furthermore, another important research design aspect was the agreement with top management for continuous negotiation of the research's use of various data sets (Burgess 1984; Taylor and Bogdan 1998). This agreement, which turned out to be satisfactory, was established since, during access negotiations it was not feasible for the researcher to identify all the data sources he would like to use. Thus, it was initially arranged that he could have access to internal documents and archives, and he could interview employees - clearly important for research validity and the reliability (Burgess 1984) - provided that he would inform the mediating consultancy and case organization management of his intentions in advance. The researcher was also requested to notify the organization of his intention to publish any articles or reports arising from this research.

3.7 Reflections on the skills and the role of the investigator

The dual role of the investigator as a researcher/consultant (Gummesson 1991) or as a participant-as-observer (Burgess 1984) requires some discussion. First, this role gave the researcher an increased level of access, since like an analyst (Gummesson 1991) he had essential documents, and official and classified information at his disposal. Furthermore, the project participant role (Gummesson 1991) enabled the researcher to contact several groups and get to know many of the company's employees, while, during to his twenty-month residency, he was able to observe at first hand many situations valuable to the research.

Second, the performance of the dual role of the researcher/consultant requires the existence of a background that appears to be particularly important, since it not only shapes the investigator's preunderstanding, before his actual engagement in the research programme (Gummesson 1991), but it also facilitates his performance in conducting the research, giving it credibility (Rubin and Rubin 1995).

The investigator earned professional membership of the Technical Chamber of Greece[40] in 1998, after the completion of a five-year, full-time BSc in Chemical Engineering at the National Technical University of Athens. Moreover, he also graduated with a Master's in Engineering

[40] Equivalent to the UK Institute of Chemical Engineering

Business Management from the University of Warwick in 1999. Between 1996 and 1998, and concurrently with his undergraduate studies, the investigator worked as a part-time employee in a medium-sized management consultancy and was involved in the development of a number of ISO 9000 quality management systems in the food, energy and utilities industries. This working experience gave him the opportunity to familiarize himself with both industrial contexts and interviewing, and auditing methodologies and techniques. In November 1999 the investigator joined his current employer, who enabled access to the case organization. In addition, the researcher, prior to entering the organization and starting the fieldwork, attended two intensive five-week seminars concerning industrial maintenance and organizational change techniques and methodologies. Between 2000 and 2004 the researcher was involved in, and in many cases managed, a number of projects, such as organizational change progranmmes, design and development of information systems, business plans, and audits in both public and private organizations.

This brief outline of the researcher's background and skills is provided as an indication of the development of at least a basic level of preunderstanding that combines both theoretical qualifications and practical experience. It can also be argued that since such an embrained (Blackler 1995) preunderstanding stems from diverse technical and managerial perspectives, the researcher needs to be aware – as far as is possible – of his pre-existing mental models (Gummesson 1991), something that is of particular importance in cases where the researcher should re-examine his assumptions going into the study, and into the interpretation of collected data. Hence, acquired general and specific knowledge (Gummesson 1991) not only allows the investigator to understand the established technology within the organizational setting, enabling the reconstruction of context, but also this knowledge, coupled with managerial skills, allows the development of a wider understanding about organizational and social aspects, such as social interaction and institutional conditions. Furthermore, knowledge of both national and technical language improves the chances of a richer interpretation of the organizational knowledge creation processes.

3.8 Data collection

3.8.1 Data sets and their role in the research

The present case research study employed multiple data collection methods with the aim of obtaining a rich dataset, as well as capturing contextual complexity (Benbasat et al. 1987; Benbasat and Weber 1996). Multiple data collection methods allowed data source and methodological triangulation (Denzin 1978; Miles and Huberman 1994; Taylor and Bogdan 1998). Collected and utilized datasets (Eisenhardt 1989; Yin 1989) and "empiric material"

(Myers 1997) included public, private, solicited and unsolicited documents (Burgess 1984), archival records, interviews, direct observation (Remenyi and Williams 1995), and participant observation (Trauth and O'Connor 1991). The documentary evidence collected or produced during the research is outlined in Table 3.1, which attempts to highlight aspects of the role of these documents within the investigation.

Table 3.1 **Collected Datasets - Documentation**

Document Name	Description	Role in the Research
Organization Charts	Past and present organization charts	Development of the organizational structure.
Corporate Purpose	Corporate purpose document	Acts as a knowledge vision
Maintenance Philosophy	Contains the high-level maintenance approach of the refinery	Insights about knowledge creating directives within the organization
Maintenance Organization Report	Detailed description of the MD	Historical and other information about the organization
Maintenance Division Skills Report	Description of the existing in-house skills	Skills are routine knowledge assets
Maintenance Strategies Report	Description of maintenance know-how	Strategies are systemic knowledge assets
Benchmark Reports	Two international refining sector Reports	Comparisons with international competitors.
Culture and Staff Satisfaction Surveys	Two cultural surveys	Insights into the organizational culture
Work Measurements Report	Description of low-level maintenance activities	Understanding of the activities and social interaction of low-level employees
Training Review	Description of local training techniques	Explains aspects of the creation of experiential and routine knowledge assets.
Existing Job Descriptions Report	Descriptions of the duties and responsibilities of each hierarchical level	Explains the roles and the interactions of the research's participants
Asset Register Audit	Description of the condition of an important database of the MD	The Asset Register is a systemic knowledge asset
Computerised Maintenance Management System Audit Report	Description of the condition and use of IT applications within the MD	The Computerised Maintenance Management System is a systemic knowledge asset
Turnaround Audit Report	Identifies improvement opportunities	Understanding of the local conditions
Collective Labour Agreement	Describes financial compensation for each hierarchical level	Insights into the hierarchical levels of the organization
Official Management Announcements	Announcements about a variety of organizational issues	Understanding the knowledge vision and the role of management
Labour Union Announcements and Newsletters	Announcements and newsletters	Insights into the socialization process.
Historical Data	Information from the official corporate web site and anniversary publications	Insights into the organizational structure, and other aspects of the knowledge creation process such as socialization
Material from presentations	PowerPoint presentations	Supportive role in cross checking information
Other BPR Internal Documents	Internal BPR documents, such as the Performance Indicators Document	Supportive role in cross checking information

The archives collected and utilized by the research are briefly presented and described in Table 3.2.

Table 3.2		**Collected Datasets - Archives**
Archive Name	**Description**	**Role in the Research**
Personnel Records	Maintenance Staff Database	Information about the background of interviewees.
Maintenance Work Records	Work Orders Archive	Word Orders are systemic knowledge assets. Insights into the synthesis of information flows and the quality of created and utilized knowledge from everyday maintenance activities
Technical Records	Technical Drawings Database	Technical Drawings are systemic knowledge assets
Maintenance Processes Archive	Describes local maintenance processes	Understanding of the normal maintenance workflow
Archive of the researcher's employer about Petrochem	The archive covers various aspects of Petrochem	Historical and other technical information
BPR Progress Reports	Weekly progress reports	Contain management's decisions for the organization.
Project Team's Internal Emails	An archive of about 700 emails	Supportive role in cross checking information
Financial Records	N/A	Secondary dataset that assisted cross checking, e.g. Increased travel expenses

Moreover, both direct and participant observation enabled the generation of important datasets. In particular, direct observation was facilitated by the fact that the researcher's office was in the administration building in the heart of the refinery, in close proximity to the offices of engineers of the Maintenance Division. This facilitated, for example, observations of the dynamics of the everyday working life. Corridor chats at coffee breaks, and over lunch, were an enriching information source in gaining an understanding of the organizational setting, the cultural values and the group social interactions. Such informal discussions were recorded in the researcher's personal diary (Symon 1998). Besides the recording of direct observations, this diary aided reflection and led to ideas that directed the research (Silverman 1999). Participant observation enabled the collection of rich and detailed data based on observations in situ (e.g. Burgess 1984). Table 3.3 outlines the datasets obtained through direct and participant observation.

Table 3.3		**Collected Datasets - Direct Observation**
Name	**Description**	**Role in the Research**
Personal Project Diary	The 250-page diary contains daily observations on various events, general information about the organization, informal discussions and opinions	An important source of information. Enables the integration of various sources into a coherent case description during the analysis stage

Table 3.3		**Collected Datasets - Direct Observation**
Notes from the Training Programme	The researcher's notes from the 5-week training programme on organizational and technical issues. The dataset recorded the opinions of various management levels	Insights into the maintenance knowledge creation process
Notes from presentations to the Maintenance Personnel	Maintenance personnel attended many presentations in small groups	Supportive dataset utilized for cross-checks
		Collected Datasets - Participant Observation
Name	**Description**	**Role in the Research**
Notes from the development of new maintenance processes	Cover discussions for the development of new maintenance processes	Understanding of information flows, and the everyday maintenance working activities
Notes with refinery Middle Management	Cover discussions for the work prioritization system. Includes opinions of other refinery Divisions about the MD	Insights into the relationships of the MD with other refinery groups.

However, when it comes to interpretative case studies, interviews are considered another primary data source (Walsham 1995b; Fontana and Frey 2000), since they have the potential to allow the researcher access to participants' interpretations. In the present research, semi-structured interviews were a very important data source (Taylor and Bogdan 1998).

The researcher obtained permission to conduct interviews with personnel from top, middle and lower management levels of the Maintenance Division. The aim was to delineate the knowledge creation process, its information flows and its influencing factors, and the interviewees' contribution in it. The intentional and systematic sampling of interviewees (Burgess 1984; Lee et al. 1991; Arbnor and Bjerke 1997) led to the identification of participants holding key positions within the organization, or who were key informants. Thus, besides maintenance personnel, interviewees included people directly involved in related activities. Such interviewees included employees from the Operations Division (OD), which benefited from maintenance activities, and interactions with them shape the social setting. In addition, interviews with consultants or other company employees not directly involved with the Maintenance Division, assisted in the development of an understanding of the knowledge creation process through the eyes of third parties.

The researcher initially planned to interview approximately twenty-five people from various divisions in the case organization. However, this number was increased (Silverman 1999), since the inclusion of additional perspectives (Rubin and Rubin 1995) was helpful in achieving of a rich description of the local conditions and the social process of knowledge creation. Thus, forty-three people were interviewed in eight months. Table 3.4 provides a list of the interviewees and shows the numbers of initial and follow-up interviews that were conducted.

Table 3.4 Table of Interviewees and Interviews

Interviewee	Initial Interview	Follow-up interview
Technical Director (CEO)	1	No
Corporate Information Systems Manager	1	1
Maintenance Manager	1	1
Assistant Maintenance Manager	1	1
Six Maintenance Department Heads	6	6
Eight Maintenance Engineers	8	8
Six Maintenance Supervisors	6	6
Two Senior Technicians	2	No
Manager of the Operations Division	1	No
Three Operations Engineers	3	3
Three Operations Supervisors	3	No
Head of the Training Department	1	No
Head of the Process Department	1	No
Head of the Environment Department	1	No
Head of the Occupational Health and Safety Department	1	No
Head of the Procurement Department	1	No
Head of the Inspections Department	1	No
Head of the Investment Programmes	1	No
Three BPR consultants	3	3
Number of Initial/Follow-up Interviews	**43**	**29**
Total number of Interviews	72	

At the beginning of each interview, the themes or topics the researcher wanted to cover were explained (Rubin and Rubin 1995). An indicative list of such topics that were used to guide the interview are presented in Table 3.5

Table 3.5 Indicative Topics and Themes Covered in Interviews

- Personal Educational and Employment Background – Past and Current Duties
- Reasons for joining the firm, selection process
- Positive and negative aspects of working in the firm
- Description of what occurs during the construction of new units
- The nature of maintenance work and its execution - what occurs during normal and emergency maintenance work
- Departmental policies, vision, mission statement, objectives
- Skill acquisition, training, job rotation
- The creation of Work Orders
- Performance management
- The role of ICT in maintenance
- Planning and scheduling activities
- Consideration of Socialization
- Relationships of the Maintenance Division with the Operations Division and with other divisions of the organization
- Relationship of the Maintenance Division with external contractors and manufacturers
- Autonomous action/teams
- Experimentation
- High and low care relationships
- Improvisation

3.8.2 Rapport establishment and data collection procedures

The establishment of rapport (Miles and Huberman 1994; Hammersley 1995) with organizational actors was of vital importance throughout the research, since it helped in the establishment of communication channels and enabled the gathering of the valuable datasets. A number of tactics contributed to the building of rapport (Taylor and Bogdan 1998). The investigator's engineering background turned out to be very important for the establishment of relationships with middle management engineers. In building relationships with supervisors, the researcher provided personal information, pointing out the working class origins of his father, since most of the refinery supervisors were of a similar age and background. This, combined with the relatively young age of the researcher (Burgess 1984) and his humble style, not only during the interviews but also during informal conversations, made him popular amongst lower management and helped establish a satisfactory level of rapport. Moreover, the investigator assisted key informants and showed an interest in participating in organizational activities ranging from fire fighting exercises to social events, such as book exhibitions and blood donations. The establishment of rapport (Taylor and Bogdan 1998) was reflected by the eagerness of senior and middle management to participate in the interviews, and even led the researcher being offered a permanent job at the organization twice, once before and once during the research interviews[41].

Data collection was based on three principles (Yin 1984): the use of multiple sources of evidence, the creation of a case study database and the maintenance of a chain of evidence. These principles, along with the adoption of an organized research protocol, contributed to the reduction of common qualitative research biases (Miles and Huberman 1994; Klein and Myers 1999). Such biases include the holistic fallacy (the interpretation of events as more patterned and congruent than they really are), the elite bias (the overweighting of data from articulate, well-informed and high-status informants), and "going native". Furthermore, the research, and consequently data collection, had an overt character (Burgess 1984; Walsham 1996; Silverman 1999), since the investigator even in informal discussions, revealed to interlocutors his academic aspirations and his access to the organization for research purposes.

In particular, the use of multiple data sources was coupled with a number of sampling strategies (Miles and Huberman 1994; Patton 1990), contributing to the avoidance of pitfalls concerning representativeness, since there was a conscious effort to sample representative informants and events. Hence, the sampling of interviewees was purposefully stratified in an attempt to surface

[41] However, the investigator refused this unexpected job opportunity for personal reasons.

subgroups and to facilitate comparisons. In addition, an intense sampling strategy was adopted in order to collect documents and archival material and record observations, so that the information-rich case would manifest the process of knowledge creation in some depth. Moreover, gathered datasets attempted to cover aspects of three kinds of events (Burgess 1984). First, routine events, such as routine maintenance events, were selected in order to provide an understanding of daily working life activities. Second, special anticipated events, such as a number of maintenance activities and social events, enlightened various aspects of the knowledge creation process and highlighted what might be considered as normal. Third, an opportunistic sampling strategy of untoward events and extreme cases, such as emergencies, allowed following new leads, confirming conclusions, and taking advantage of the unexpected.

Two distinct periods can be identified in the data collection process. The first data collection period started in January 2000 and lasted for the twenty-month period of residency of the researcher in the case organization, enabling the development of a deep understanding of everyday events and activities. During this period, documentary and archival records were gathered. Direct and participant observations were also conducted, along with a limited number of guiding interviews. The second data collection period was from May 2002 to December 2002, after the researcher's deliberate seven-month absence from the organization in recognition of the potential impact on social and institutional relationships, and consequently on the collected datasets. This tactic allowed the reduction of biases stemming from the effects of the site on the researcher (Miles and Huberman 1994; Klein and Myers 1999), such as "going native". In addition, the researcher selected this particular period for his return to the organization with the aim to conduct the main body of interviews and to clarify gaps in the data already collected and to crosscheck discrepancies.

A significant part of the documentary evidence gathered during the first period of the research were from secondary sources (Burgess 1984), such as documents, archives or other material, and had undergone at least some sort of processing, having been prepared for a variety of purposes and having been based on different assumptions, thereby weakening them from a research perspective (Miles and Huberman 1994; Klein and Myers). Therefore, a critical perspective was adopted not only for these data, but also for primary data, gathered first-hand by the researcher. However, the dual role of the researcher enabled him to understand many of the underlying assumptions and perspectives of data collected from secondary sources.

The researcher also believes that his effect on the case (Miles and Huberman 1994) was significantly reduced, thus ensuring the gathering of quality datasets. There are two reasons for this assertion. First, the researcher remained long enough in the case organization and made his intentions known unequivocally. Second, and since interviews were a primary data source, the researcher used a common tactic to check on any impact he might have had. He co-opted two key organizational informants (Miles and Huberman 1994), whom he asked to be attentive to his influence on the case and its participants. For example, the researcher asked a top manager during the guiding interviews to provide feedback about his influence upon interviewees. The informant, having checked with colleagues, verified that interviewees were not suspicious of his role. This check was performed again prior to the main body of interviews. The second check confirmed that the interviewees understood the researcher's academic intentions.

The data collection procedures were also flexible enough to permit the researcher to follow up any surprising issues that surfaced (Miles and Huberman 1994; Rubin and Rubin 1995). For example, one day the investigator heard from a loudspeaker an announcement about the existence of a bonus scheme, despite the fact that documents and informal discussions with personnel were pointing to the non-existence of an official reward system of this kind. This announcement was recorded in his personal diary and was used during the interviews to clarify the corporate reward system.

Furthermore, the investigator adopted a flexible, iterative and continuous[42] research approach (Rubin and Rubin 1995). Hence, participation for personnel in the semi-structured interviews was optional (Silverman 1999), and conducted in an informal setting, where the respondent was alone with the researcher. Moreover, interviews were not recorded, despite the researcher's initial intention, since there was a widespread fear amongst members of top and middle management that any opinions they expressed could possibly be used against them (Taylor and Bogdan 1998). Indeed, it should be acknowledged that management's initial suspicion was not totally groundless. The investigator identified at least two contributing reasons that explain concerns regarding the recording of interviews. First, the imminent national elections in Greece were expected to result in radical changes to the executive board, and consequently to all other hierarchical levels of the company. Unofficial discussions revealed that such political interventions had been common in the organization. Second, fears were also amplified by repeated government announcements about plans for privatization, which would result in large groups of employees becoming redundant.

Notwithstanding, detailed notes were taken during interviews, as this was not considered a threat by management and other employees. These notes were used by the investigator to reconstruct the interview immediately following. At the conclusion of each interview,

[42] The principle of continuous interviewing design suggests that the questioning is redesigned throughout the project.

participants were asked if they would like to have a copy of the researcher's notes. However, only one interviewee asked for a copy, but after examination, did not keep it.

At the beginning of each interview the researcher also clarified that anonymity would be maintained and any material provided would be treated with confidentiality (Rubin and Rubin 1995). Participants were also informed about the interview length. The average interview lasted approximately two hours. However, other interviews, which were held mainly with outliers, lasted only thirty minutes or so. When the researcher did not manage to cover all the necessary topics during the first interview, he arranged a follow-up at a mutually convenient date.

The investigator attempted to manage interviews by trying to be reassuring and non-judgemental. By demonstrating patience, he also allowed time for people to talk and tried to pay attention to the words they used (Taylor and Bogdan 1998). However, the interviewer also probed participants (Rubin and Rubin 1995) by asking them to express their opinion on anonymous statements given during other interviews or observations made in an effort to cross-check information (e.g., Denzin's (1978) concept of triangulation). This approach was adopted, having in mind the principle of suspicion for conducting and evaluating interpretative field research (Klein and Myers 1999).

In general, the organization of the semi-structured interviews turned out to be a demanding process, based on the researcher's knowledge of the social situation (Rubin and Rubin 1995). Many times the wording of the question turned out to be crucial (Burgess 1984). Descriptive questions (Taylor and Bogdan 1998) that were formed with the help of material collected during observations were used in many instances (Silverman 2001), especially at the beginning of the interviews, while in some other cases, participants were asked to provide explanations about various documents. Interviewees were also motivated not only to narrate episodes of their working life, but also to reflect and comment on them.

3.9 Data analysis

Data analysis - the dynamic and creative process through which the researcher gained understanding of the phenomena under study and refined his interpretations (Taylor and Bogdan 1998) - is a process that did not occur in isolation from, but along with, data collection. Analysis consisted of the examination, categorization, tabulation and recombination of the evidence being gathered (Yin 1984). For example, the examination of the archive with the internal emails of the BPR project team was not considered as a relevant data source in relation to the investigative focus and this reduced its use to the supportive crosschecking of other information.

Moreover, the preparation of tables, such as those concerning the departments and the hierarchical levels of the case organization, required the tabulation of data selected from different documents. Other tables, such as those concerning the contribution of the workload to the knowledge creation process, the places where repairs are conducted, and the questions and issues that allow the formulation of repair concepts, required the combination of information obtained from sources, such as internal documents, with empiric material collected in interviews.

The research used a combination of general analytic strategies (Yin 1984; Arbnor and Bjerke 1997) for the analysis of the case study evidence. Hence, reliance on expressed theoretical propositions (Yin 1984), the research questions, helped the researcher focus on certain types of data and guided the analysis. For example, the research focused on the acquisition of maintenance skills and the use of databases, which are considered as knowledge assets of the knowledge creation process within the case organization. Simultaneously, the second supportive analytical strategy was the development of a case description related to the flow of maintenance work. Although the objective of the case study was not descriptive, this descriptive approach enabled the identification of apparently casual links within the knowledge creation process, its context and its knowledge assets. Indicatively, the research presents how personnel acquire tacit knowledge in the form of maintenance skills though a number of face-to-face interactions. This enables the identification of links between the socialization stage of the knowledge creation process with its content, in other words the acquired maintenance skills, within a context that is shaped by face-to-face social interactions.

Having established general analytic strategies, the research adopted a special type of pattern-matching strategy, an explanation-building mode of analysis, which also contained some elements of chronological analysis (Yin 1984). Such analysis interprets the case using the model of dynamic knowledge creation (Nonaka et al. 2001a), stipulating a set of casual links about it. The analysis also utilized the knowledge activism framework (Von Krogh et al. 1997) in order to support interpretations concerning individual or group action and interaction. Furthermore, other concepts and models, such as Feldman's (1976; 1981) three-stage model for socialization and Von Krogh's framework (1998) on care relationships, played a secondary and supportive role in the analysis.

At this point it must be acknowledged that such a mode of analysis is inclined to some interpretive discretion on the part of the investigator, who either can claim a pattern match or a pattern violation (Yin 1984; Lacity and Janson 1994). For example, one important source of bias could stem from the translation of the interviews from Greek into English and this could degrade meanings. In order to deal with this problem, the researcher has sought on numerous occasions the advice of a Greek speaking academic researcher in the field of English literature. Additionally, the researcher, in an effort to minimize arbitrary interpretations, utilized metaphors and analogies as a mechanism that facilitated data reduction and enabled the connection of findings to theory (Miles and Huberman 1994; Myers 1997). The metaphor/analogy mechanism provided the researcher with this pattern-matching tool, since it suggested the utilization of definitions and casual propositions provided by the model of dynamic knowledge creation (Nonaka et al. 2001a), such as the knowledge-creating episodes that are involved in each stage of the SECI process (Nonaka et al. 1994), for making sense of the data (Weick 1988; 1993; 1995). In the present thesis the sensemaking of data and other collected empirical material was a process of meaning construction on how knowledge creation occurs through the daily flow of maintenance work, which is driven by the beliefs of the researcher. In this sensemaking process the research framework assisted the researcher to focus on cues that constitute the social reality (Berger and Luckman 1966) of the knowledge creation process. These assertions constitute an important link between this research and Weick's sensemaking concept (Weick 1995).

Since the data obtained was voluminous and varied, this made both data collection process and analysis time-consuming and demanding (Cavaye 1996). Data analysis involved data reduction through a process of data selection, simplification, abstraction and transformation (Miles and Huberman 1994; Ryan and Russell Bernard 2000) in order for conclusions to be drawn. Besides the careful reading and rereading of collected data, the early analysis steps also involved coding and memoing (Miles and Huberman 1994), especially when it came to dealing with material obtained through interviews. In fact each interview answer was ascribed with one or more key words, in an informal coding process, which allowed the researcher connect this material to the above-mentioned case description. Then, selected interview quotes were used in order to fortify the presentation of the maintenance flow of work within the case organization. In addition, data analysis tactics for the generation of meaning involved making comparisons and building a logical and coherent chain of evidence (Miles and Huberman 1994) that protected the research from drawing inferences from non-representative processes. For example, the maintenance strategies report was compared with material obtained through interviews allowing the realization that the case organization operates concurrently with a reactive and a proactive maintenance mode. Furthermore, an attempt was made to draw conclusions, based on the principle of plausibility (Miles and Huberman 1994; Walsham and Sahay 1999), such as the proposal for the distinction of experiential knowledge assets into positive and negative ones in the concluding chapter of this thesis.

3.9.1 Unit of analysis

The industrial complex of the largest refinery of the public petrochemical group of Petrochem provides the context for this research. However, the unit of analysis relates to just the Maintenance Division of this refinery and its six functional departments - an organization of approximately three hundred people. The research focuses on the knowledge creation processes within this particular organization and the majority of the interviewees came from its top, middle and lower management. In addition to these interviews, a large number of datasets associated with the organization, and the knowledge creation process associated with its maintenance activities, were collected during and after the Division's BPR project.

3.10 Reflections on the quality of research conclusions

In order to assess quality in case study research, many criteria have been proposed (Yin 1984; Drucker 1987; Gummesson 1991; Miles and Huberman 1994; Arbnor and Bjerke 1997; Silverman 1999; 2001; Klein and Myers 1999). Thus, according to Drucker (1987) and Gummesson (1991), the researcher should satisfy certain qualities and requirements, such as honesty and a preunderstanding of the phenomena under study. In addition, the researcher should have adequate access and should present their paradigm with commitment and integrity. The research project should also be dynamic, possess credibility, allow readers to draw their own conclusions, and most importantly, it should make what is said to be a valid contribution.

The present study was based mainly on an established set of four criteria (Yin 1984), namely construct validity, internal validity, external validity and reliability. The use of multiple sources of evidence, in a manner encouraging convergent lines of enquiry, contributed to the fulfilment of the criterion of construct validity. For the same criterion, the researcher established a chain of evidence, to the extent possible, since while in some cases he had access to data sources, it was infeasible and inappropriate for him to keep copies of confidential documents. Moreover, the researcher attempted to test the criterion of construct validity by providing a draft of the case study report to two key informants (Miles and Huberman 1994; Silverman 1999), one from the mediating consultancy and one from the case organization. Both of these informants were positive about the content of the report, one of them commenting that the report was resourceful and provided many insights.

As far as the criterion of internal validity (Arbnor and Bjerke 1997) is concerned, something that is often linked to credibility and authenticity (Miles and Huberman 1994), the research attempted to fulfil it with the consistent adoption of an analytical strategy and an explanation-building mode of analysis (Yin 1981; 1984). This analysis utilized context-rich and meaningful descriptions which, coupled with triangulation among complementary methods and data sources (Denzin 1978), produced generally converging and internally coherent conclusions. The researcher also endeavoured to link conclusions explicitly with exhibits of condensed/displayed data. However, the analysis process did not remain without some areas of uncertainty. Perhaps the most important area of uncertainty concerned the assignment of meanings of interviewees during discussions about experiential knowledge assets, given their intangible nature. The researcher attempted to reduce this source of uncertainty by performing theoretical triangulation (Denzin 1978) with the use of frameworks concerning trust (Newell et al. 2002), care (Von Krogh 1998) and improvisation (Moorman and Miner 1998). Another equally important area of uncertainty concerned the roles of individuals within the knowledge creation process, which contribute to the shaping of the social context. This perceived weakness of Nonaka's framework (Nonaka et al. 2001a) was addressed by combining with it the knowledge activism framework (Von Krogh et al. 1997).

The third case study research criterion, that of external validity (Arbnor and Bjerke 1997), deals with the problem of knowing whether a study's findings are generalizable beyond the immediate context. The researcher does not claim an automatic generalization of the research conclusions, since he did not have the opportunity to use replication logic. However, from his professional experience he believes he can assert that there is plausibility in the conclusions. More specifically, conclusions regarding knowledge creation and its relationships with its context and its knowledge assets are likely to be transferable to other maintenance organizations, and not necessarily confined to oil refineries per se. Some of the conclusions may also be applicable to other kinds of project-based organizations, however, this is an assertion that should be treated with much caution. For this reason the researcher has attempted to provide adequate information about the sampling process, the setting, and history in order to allow readers to assess the potential transferability and appropriateness of the conclusions. The aim is to offer a level of usable knowledge that raises consciousness, develops insights and also provides local and specific knowledge, such as corrective recommendations and specific action images, in other settings.

Reliability, which is often linked to dependability and auditability (Miles and Huberman 1994; Silverman 2001), is the criterion that assesses whether the process of study is consistent, across researchers and methods. The researcher attempted to fulfil this criterion by using a case study protocol of methods and procedures and by developing a case study database (Yin 1984). He also paid particular attention to ensure that the features of the study design were congruent with the research questions, while the research design enabled the collection of data across the full range of the appropriate settings, times, and respondents implied by the research question.

3.11 Summary

This chapter has delineated the adopted definition of the term "process" (Van de Ven 1992) by the present research and has argued about how knowledge creation processes should be investigated. This approach to process inquiry, along with the theoretical construct, Nonaka's framework (Nonaka et al. 2001a), through which collected data were interpreted, indicate the selection of an interpretive (Chua 1986) case research strategy (Benbasat et al. 1987). Having established the philosophical and the methodological assumptions of the research, the chapter presents the research design, starting with an explanation of the benefits arising from the opportunistic selection of the single research site and a description of how the researcher negotiated and obtained access to this organization. Reflections on the researcher's skills and background have provided evidence of his increased preunderstanding of both the organizational and social setting. Subsequent sections have provided a detailed description of the manner in which data were collected and their role in the research. Particular attention has been paid to the establishment of rapport prior to the description of the data collection procedures. The unit and the mode of analysis and the case study assessment criteria (Yin 1984; Klein and Myers 1999) and their fit with the general research design have also been explained. Next, we turn to the case organization itself.

4

Doing the dirty job: Petrochem and its Maintenance Division

4.1 Introduction

Having established in chapter three both the nature of process inquiry and the approach being adopted in exploring knowledge creation processes, this chapter introduces the case organization by presenting basic aspects of its business and project layers (Nonaka 1994; Ekstedt et al. 1999) - its organizational structure and its workload - between which the knowledge creation process unfolds and interacts.

The description of the business layer begins with an overview and brief history of Petrochem. This is followed by a description of the educational profile and training policy of Petrochem, while a third section focuses on the existing staffing procedures. Then, the chapter presents the venues of the refinery A, the flagship of Petrochem. The following section introduces the departments of the Maintenance Division (MD) of this refinery, which are the main actors of the knowledge creation process examined in the present thesis. The bureaucratic hierarchy of the MD is then highlighted.

Having described various aspects of the business layer that supports the knowledge creation process, it is prudent to point out some characteristics of the workload of the case maintenance service organization, which is one of the driving forces of the knowledge creation process.

Finally, the chapter includes two sections that set the background for developing an understanding of the knowledge creation process and the knowledge base of the organization (Nonaka 1994). One describes important elements of the Computerized Maintenance Management System (CMMS) and of the other maintenance-related software applications, and the other delineates important cultural elements, in particular, cultural embedding, articulation and reinforcement mechanisms (Schein 1985) within Petrochem and the MD.

4.2 Overview and brief history of Petrochem

Petrochem is a group of eleven companies owned and controlled by the Greek State, despite the steps taken for its emancipation from the governmental influence since the beginning of the 1990s. Petrochem group, which is headquartered in Athens, is the largest fully integrated, downstream oil industrial and commercial enterprise in Greece in the petrochemicals industry and has significant activities in Eastern Europe, in the eastern Mediterranean region and in the Middle East. The parent company of the group, Petrochem, is managed by a board of directors, and is, either directly or indirectly, the sole or the majority shareholder in the subsidiaries or affiliated undertakings. Petrochem is organized by way of a multidivisional structure and its industrial venues include three refineries, namely Refinery Divisions A, B and C. The present research focuses on the flagship of its refining operations, namely refinery A. Important milestones in the history of Petrochem group are presented in Figure 4.1.

Petrochem is one of the largest five hundred European companies and one of the top ten petrochemical companies in the EU, with 3.2 billion Euros in revenues and more than 3,300 employees in Greece and approximately 1,200 all over the world. Amongst other activities the group is involved in crude oil refining, the provision of engineering services, such as the construction and operation of pipelines, and the production and trading of all types of energy.

The size of the group, in combination with the small domestic market, the limited competition and continuous technological investments enabled Petrochem to occupy the leading position in all of the sectors in which it is active. Thus, for example, Petrochem has the largest marketing network among domestic refining companies, which covers 75% of domestic market requirements[43]. Moreover, the group established the first private electric power production unit in the country. Amongst the various investments of Petrochem is the acquisition and company-wide implementation of SAP R/3 ERP system. An executive officer of Petrochem gave the following explanation for the acquisition of the ERP system:

> "Take Exxon for example, its margins for profit from crude production to products distribution are vast. The only area in which they could cause problems to competitors is the oil refinement. This happens due to the fact that there is overcapacity for oil refinement worldwide. Hence, refineries that will make better use of their resources and will reduce costs will survive. Big multinational

[43] The three refineries of Petrochem have also a vast storage capacity, which enables the regulation of market prices.

companies fight competitors with large investments on Information Systems. This investment is an one-way road for us".

Figure 4.1	**Milestones in the History of Petrochem Group**
Year	**Event**
1975/1980	The Greek state acquires refineries A & B
1981/1990	Establishment of a series of companies activated in hydrocarbon and natural gas exploration and production, petroleum engineering and in the marketing of petrochemical products.
1991	Deregulation of the Greek petroleum market, following EU legislation, terminates the control of the Greek state since 1956.
1998	• Establishment of Petrochem group with merger of all the State owned petrochemical companies. • Trading of 20% of the new company's shares in both the Athens and London Stock Exchanges. • Unification of five different salary systems of the merged companies with simultaneous upgrade of the fringe-benefit programmes with a view to foster good labour relations (Annual Report 2000). Amongst others, benefits included additional insurance, a medical programme, free transportation to the refinery, summer camps for employees' children, scholarships for top students, and financial assistance for learning foreign languages.
1999	The executive board launches a long-term investment plan that aims at stabilizing the group's national and international position and at ensuring profitability and competitiveness in the global operating environment[44].
2000	Company-wide implementation of SAP R/3
2001/2002	Completion of technological projects mainly in the refining sector, in the production of electricity, in hydrocarbon exploration at home and in the expansion of activities in Europe. Enhancement of the refining capacity and improvement of the product slate.
2003	A strategic partner acquires 20% of the Petrochem's share capital

4.3 Educational profile and training policy of Petrochem

The educational profile of an organization's personnel is often used as a rough indicator of the quality of the business layer. As the spectrum of the employees' educational profile reveals, Petrochem has achieved a good balance between university graduates and employees with lower qualifications, since 711 employees are university graduates, 437 are graduates of a polytechnic school, 1724 are high school and technical high school graduates, while a very small percentage, approaching retirement, has received only basic education.

Furthermore, an objective of Petrochem is the constant upgrading of personnel in terms of both its general education and professional expertise (Annual Report 2002). To this end, group companies have instituted policies covering foreign language learning, participation in seminars

[44] Since 1998 crude price fluctuations in combination with the global economy recession caused the fall in refining margins. However, the adoption of the euro, the de-escalation of inflation, the inflows of EU funds, and the 2004 Olympic Games created a positive business climate for Petrochem. Hence, all these factors created a challenging climate for the growth of entrepreneurship in Southeast Europe.

and conferences in Greece and abroad, training programmes, in-house library facilities and subscriptions to professional periodicals and associations. As an indication, in 2001, employees attended two hundred and four seminars, while the group organized twenty-eight training trips abroad. In addition, Petrochem has spent a significant amount in upgrading libraries, in magazine subscriptions and in memberships of various professional associations.

4.4 Staffing procedures at Petrochem

Staffing procedures are a constant source of renewal for an organization's business layer, preparing newcomers for their working life through anticipatory socialization (Feldman 1976; 1981). However, employee preparation does not appear to function adequately in Greek public organizations. Thus, personnel employments at Petrochem are conducted and controlled by ASEP[45], the independent non-governmental authority created in 1994 by the Greek State. ASEP's main responsibility is the selection of human resources for all public companies though a variety of bureaucratic assessment procedures, giving an end to political appointments. For example, a supervisor from the Static Equipment Department narrated a story indicative of the employment climate prevailing at the refinery prior to ASEP. The story referred to an incident that occurred approximately fifteen years ago: "I opened the door of the machinery shop and I realized that the room was crowded. My crew had ten people and in the room there where at least twenty. "What happened?" I asked one of my team members. "Don't you know? The government has employed these people!", he replied. Maintenance supervisors, during informal discussion, explained that for many decades governments decided to massive employ many people in the public sector, just a year or two before the elections. This caused many problems in the refinery.

The introduction of ASEP improved this situation, but some problems remained. An engineer from the Static Equipment Department explained:

> "ASEP usually responds slowly to our demands, causing some problems. [...] For example, the employment of a new welder may take up to six months. So until then the department adjusts its resources accordingly in order to manage the maintenance workload. [...] Either we train a new worker, or the existing welders work overtime. [...] Another problem with ASEP is the difficulty to control the qualifications of the new employee. [...] Last year we requested an arc-welder and ASEP

[45] Besides the creation of ASEP, many Greek governments since early 1990's, have made efforts without significant progress to modernize the existing Labour legislative framework, the creation of which can be traced back in mid 1920s and enforces privileged job security for the employees in public organizations. A top manager noted in an informal discussion that job security acts as a demotivator in public organizations, since it deprives the punishment of undesired work performance and behaviour.

sent a blacksmith. So we trained him from the beginning so that he could become a certified welder".

4.5 Refinery A and its venues: the flagship of Petrochem

Refinery A is located in southern Greece and it is one of a complex[46] type, as well as one of the most technologically advanced refineries in Europe (1999 and 2001 Solomon Benchmark Reports for Petrochemical Industries). It converts crude oil into more than 2000 refined products ranging from car fuel to special army and aviation fuels. Its activities, which range from the reception of crude oil for storage, include all petroleum handling and refining operations, to the shipping of the refined products. Hence, refinery A employs all existing separation, conversion and treating processes, feedstock and product handling, and auxiliary facilities. Its most important advantage, the fluid catalytic cracker (FCC), which processes residues and produces expensive white products, was constructed in late 1980s during a major revamp that transformed refinery processes. During that period the refinery almost doubled its personnel in less than two years. Between 1998 and 1999, the refinery was further revamped in order to produce gasoline according to European Union specifications for auto-oil 2000. Hence, many technological generations coexist, as a supervisor from the Static Equipment Department explained:

> "As you see we've one distillation unit built in early 1970s and one that was built last year, but we maintain them properly irrespective to their differences. [...] Yes, the refinery is some sort of a technological museum, but it is in a good shape".

Administration, production and maintenance activities are performed at refinery A occupying 80 million square meters and containing more than forty production units and a tank farm with approximately 100 tanks. The heart of the refinery contains all administrative, control and supportive functions buildings, and is surrounded by the production units. The old administration building, which is located at the centre of the refinery, hosts the offices of the refinery's top management, a good and updated technical library, a large meeting room and the canteen.

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[46] The crude oil feedstock and the slate of petroleum products determine a refinery's processes and consequently its technological complexity. The geographical location of Greece allows the supply of various crude oils such as from the Caspian Sea and the Middle East.

Refinery A operates on an integrated basis with refineries B and C, which have much simpler technology, and this requires frequent travelling by middle management personnel for the resolution of production or technology transfer issues. The operations manager noted:

> "Personnel are in constant movement. [...] Engineers travel to the other refineries or very often we host meetings with visiting colleagues. [...] When the other two refineries need to upgrade their units they visit us".

4.6 The clones of the empire: the maintenance division and its departments

The Maintenance Division (MD) of refinery A employs 272 people and consists of six departments, the Planning Department (PD), which is officially responsible for the planning of all maintenance activities through the Maintenance Work Request/Work Order System, the Electrical (ED), the Instruments (ID), the Static and the Rotating Equipment Departments (SED & RED respectively), and the Warehouse Department (WD) that supplies the necessary spare parts. Information collected about the departments of the MD is presented in Figure 4.2.

The responsibilities of the ID and the ED extend beyond the normal maintenance activities[47] (1999 Salomon Benchmark Report for Petrochemical Industries). Hence, the ID has incorporated a planning function with the introduction of a crew coordinator - a competing position with respect to the PD. In addition, ED personnel are involved both in the operation of the units they maintain with the Electricity Distribution Team, and in the construction of new units with a dedicated team, the New Installations Team, which collaborates with the Division of New Projects. The ED head explained:

> "The personnel of the ED are responsible not only for operations, but also for the maintenance of the established substation network at the refinery, since it's difficult for us to separate these two functions (operations and maintenance)".

The head also noted about these activities that enhance requisite variety:

> "The reliability of electrical equipment is excellent and therefore we find the opportunity to occupy excess personnel with the operation of the substation network and with the new projects of the refinery, which is an economic benefit for the refinery".

[47] The British Standard Institution (BSI) defines maintenance (BS 3811) as "the combination of all technical and associated administrative actions intended to retain an item, in or restore it to, a state in which it can perform its required function".

Figure 4.2 The Departments of the Maintenance Division

Department	Departmental Responsibilities	Established	Number of crews	Average employment time[48]	Other information
Planning	Short-, medium- and long- range maintenance planning and scheduling	Since the beginning of the company.	None	80% of personnel have been employed for more than ten years.	Planning personnel are called "planners" Shutdown planners deal with the long-range planning of complex refinery repairs performed every 4 years and require a general refinery shutdown
Static Equipment	Combines specialised activities that demand certified labour, such as welding, and totally unskilled activities, such as insulation and other general duties	In 1987 with the division of the Department of Mechanical Equipment	12	80% of personnel have been employed for more than ten years.	
Rotating Equipment	Maintenance of both complex and simple equipment with rotating parts.	In 1987 with the division of the Department of Mechanical Equipment	10	Three people out of five have been employed for more than ten years	The department owns the Maintenance Archives with technical drawings
Instruments	Maintenance of mechanical and digital instruments and the operation of the instruments workshop	In 1987 with the division of the integrated Electrical and Instruments Department	10	80% of personnel have been employed for more than ten years.	Polytechnic school graduates occupy the lower management positions of the supervisors and the crew coordinator.
Electrical	Maintenance of the refinery substations and all electrical equipment	In 1987 with the division of the integrated Electrical and Instruments Department	6	99% of personnel have been employed for more than ten years.	The Electricity Distribution Team operates the substations The New Installations Team constructs new units
Warehouse	Raises purchasing orders for spare parts, receives, stores, and delivers the spare parts.	Since the beginning of the company.	2 Sectors		Collaborates with the Procurement Division

A local peculiarity of the MD structure concerns division of labour (1999 and 2001 Solomon Benchmark Report for Petrochemical Industries). Hence, the old Department of Mechanical Equipment was divided into two other departments, dealing with the maintenance needs of static and rotating mechanical equipment respectively. The SED head explained:

> "This division occurred after the 1987 refinery revamp that tripled the refinery equipment and gave a solution to the problem that one department head couldn't control so many (senior and junior) engineers".

[48] According to the Maintenance Staff Database

However, a senior consultant's comment reflects that the organization responds to environmental fluctuations as a typical bureaucracy (Weber 1947) with the creation of more hierarchical levels and similar departments:

> "To me this is an unnecessary specialization, since the only distinction lies in some of the measurement methods utilized by the two departments. Besides at the second refinery of the group there is no such distinction and they seem to be doing fine".

Furthermore, after the 1987 revamp a similar division of the integrated Electrical and Instruments Department caused the creation of the ED and the ID due to an increase in the workload. The ED department head explained that initially the ED consisted of a manager, an engineer, a couple of supervisors and a group of technicians, but after the 1988 nationwide electricity blackout, which was the decisive incident for the construction of the substation network with autonomous electricity production units for the protection of the refinery from similar occurrences, many new employees were added.

4.7 Organizational hierarchy within the maintenance division

Petrochem's Collective Labour Agreement and the organizational chart reveal that the MD contains eight hierarchical levels, which, similar to all Greek public organizations, are connected to specific salary categories and compulsory salary increases, while promotions are linked to seniority. Despite the fact that the number of levels is larger than other refineries (1999 Salomon Benchmark Report for Petrochemical Industries), this is largely due to the refinery's technological complexity. Figure 4.3 summarises information collected about each hierarchical level, highlighting existing obstacles to autonomous action and career prospects.

Employees at the technologist level, who are polytechnic school graduates, cannot be promoted to more senior positions[49]. A PD technologist said:

> "After the completion of my studies at the polytechnic school here, I completed my masters degree in UK and I became a chartered engineer there. Then, I came back but my qualifications weren't recognised by the Greek State. […] I've been working here for almost thirteen years and I know that for the next thirteen years I'll remain in the same post".

[49] Greek law maintains the distinction between polytechnics and universities

Figure 4.3 **Hierarchical Levels of the Maintenance Division**

Position	Management Level	Educational Level	Employment	Authorities/ Responsibilities	Development Prospects
Maintenance Manager	Top	Chartered engineers[50]	More than 15 years - Imposed by Greek legislation	The only position that approves budgets. The only link of the MD to the executive board.	No limit
Assistant Maintenance Manager	Top	Chartered engineers	More than 15 years	The same with the maintenance manager	No limit
Department Head	Middle	Chartered engineers	More than 8 years - Imposed by Greek legislation	Authorises all maintenance works	No limit
Engineer	Middle	Chartered engineers	12 years, on average	Authorises all maintenance works	No limit
Technologist	Middle	Polytechnic school graduates	10 years, on average	Authorises some maintenance works	No further development, according to national labour legislation
Supervisor	Lower	Technical or Navy Technical school graduates	23 years, on average	Cannot officially authorise maintenance works	Only ED and ID supervisors, who are polytechnic school graduates can move to the next level
Senior Technician	Non-management position	Entered the refinery as unskilled workers and acquired skills within the company	18 years, on average	Executes all maintenance works	Cannot progress further
Technician	Non-management position	Skilled and unskilled workers The vast majority has at least one certificate for their qualifications[51]	-	Executes some maintenance works	Progress depends on initial qualifications Cannot progress further than the supervisors' level

Potentially, this situation can also influence individual commitment (Blau et al. 1993) and motivation. The RED head added:

> "The problem with technologists is a problem for many departmental employees who aren't allowed to undertake significant responsibilities, despite the fact that they're competent".

In addition, the senior technician's level reveals an interesting local particularity, since in other European refineries senior technicians are only technicians with greater experience (1999

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[50] Only university graduates with a Master's Degree can become chartered engineers, according to current Greek legislation. The Technical Chambers of Greece, the equivalent organization for the UK Institute of Chemical Engineering, does not subscribe members with other than these qualifications, despite the directives of the EU.

[51] According to the Maintenance Staff Database

Salomon Benchmark Report for Petrochemical Industries). The assistant maintenance manager explained the creation of this position by top management:

> "The position of the senior technician was created in order to reward some technicians who were very competent in order to become supervisors, but lacked the necessary typical qualifications according to law. [...] Supervisors are usually technical school graduates, while senior technicians entered the refinery as unskilled workers and they acquired their skills in here".

Moreover, the SED head explained:

> "Senior technicians substitute for supervisors in many cases and they enjoy an increased level of autonomy".

4.8 The maintenance workload: opportunities to act and improvise

Having described elements of the business layer of Petrochem and its MD, this section attempts to deal with some important aspects of the maintenance workload or the project layer - the projects in which the business layer is involved. The maintenance workload, and in particular the actual or potential occurrence of equipment failures, defines the MD project.

The MD is responsible for the maintenance of all equipment within refinery A: the maintenance of all production units, the tank farm, and the administration buildings. Hence, the Division maintains more than a hundred thousand distinctive pieces of production equipment spread across an area of a few square kilometres.

A significant part of MD activities concerns the construction of new or the modification of older units. In some cases maintenance personnel occupied in such activities reaches thirty percent of the existing workforce. This participation in non-maintenance activities also promotes requisite variety (Ashby 1957), since it is a constant source of opportunity for the acquisition of new knowledge and for the different and flexible application of existing knowledge.

This section foresees on three basic characteristics of the maintenance workload, mainly for their interrelation with knowledge creation processes, and does not attempt to describe other non-maintenance activities of the MD. First, the frequency of maintenance faults determines the existing opportunities for maintenance personnel to acquire real and virtual world knowledge via a "learning by doing" process (Nonaka 1994). Then, the preventive or reactive nature of the maintenance workload, in relation to the established, official or unofficial, departmental policy for its management, define time-availability for problem framing and developing a working solution. This shapes the repair organization and influences the quality of maintenance knowledge that is created. The nature of the workload combined with the existing maintenance policy leads to a sense of urgency and chaos in MD (Nonaka 1988a; 1994; Senge 1990b; Leonard 1998). This influences team building when the selection of employees with required skills is so important.

The investigation revealed that the maintenance workload vary considerably across the four maintenance departments that execute repairs, as indicated in Figure 4.4, which also attempts to associate the various characteristics with the development of preventive maintenance routines.

Figure 4.4 **The Maintenance Workload**

Department	Characteristics of the workload				Development of preventive maintenance routines
	Nature of workload	Policy	Equipment	Execution of works	
SED	Mainly corrective, its execution can be deferred for a later time.	Many cases are treated as emergencies due to environmental and safety impact.	Not complex equipment. Many equipment pieces are of gigantic sizes.	Both in workshops and in the units. Use of contractors is not often.	Limited
RED	Mainly corrective. Frequent Emergencies.	Installed spare equipment often provides the required time to respond.	Moderate complexity equipment	Both in workshops and in the units. Support of contractors is often.	Only for some important equipment categories
ID	Both corrective and preventive. Often Emergencies.	Development of a preventive maintenance philosophy. All incidents are considered as emergencies. Large quantities of instruments are kept in the Warehouse	Maintains 30.000 instruments of various functions, sizes and technologies	Both in workshops and in the units. Support of contractors is often.	For the majority of instruments
ED	Small workload in comparison to other departments	Development of a preventive maintenance philosophy. Multiple redundancies in electrical equipment allow the execution of works minimizing their potential impact	Complex but very reliable equipment.	Mainly at the units. Support of contractors is often	For the majority of critical equipment categories

The SED, in comparison to other departments, and excluding the piping network, is responsible for a number of refinery assets of gigantic size. The SED head explained that the workload of his department includes corrective maintenance works, which could be executed without any particular urgency:

> "The vast majority of our workload is corrective. [...] A great part of it can be deferred for a later time".

But then, referring to the frequency of the incidents and the departmental policy, he added:

"These incidents are treated as real emergencies. [...] Many breakdowns associated with the installed piping and the vessels of the refinery are leakages with impact on the environment and on safe working conditions and it's the management's wish to comply strictly with legislation. [...] There's a constant inflow of such corrective works and personnel are quite used in their prioritization, planning and scheduling. [...] We use external contractors but not very often, since we've developed all the required skills and specialties in-house".

However, things at the RED are different. A RED engineer noted the frequent opportunities of his personnel to practice:

"We're responsible for more than a thousand pumps of various sizes and this ensures that the (pump) workshop is always busy".

In addition, the RED head stated concerning the nature of departmental workload:

"The workload of our department is mainly corrective in nature. Real emergencies are frequent, but a great percentage of it (workload) can be executed at a later time. [...] Emergency incidents are impossible to be scheduled. [...] We deal with this problem with practical forecasting of the average workload level. [...] It's possible to reduce this type of workload with the use of preventive routines. So far, we have preventive maintenance techniques only for expensive pieces of equipment, such as pumps and compressors. However, in the past we faced difficulties with some machine operators who didn't like interruptions to their production schedule for periodic maintenance".

The RED head explained the departmental policy for workload management:

"Top management is afraid of the possible consequences (of an emergency damage) especially on employees and disrupts our normal working activities until the resolution of the breakdown".

Notwithstanding, he noted the existence of a common reactive departmental working practice, which helps them cope with uncertainty. Thus, they manage to defer a great percentage of the corrective workload, due to the existence of installed spare equipment, and in doing so they gain valuable time to enable the proper identification of faults, thereby counteracting the possible consequences of a lack of an extensive preventive maintenance programme.

The situation with the workload of the ID is substantially different, due to the department's responsibility for the maintenance of approximately thirty thousand installed instruments of various functions and sizes. The department head explained:

"We're involved in emergencies more than any other department. [...] Corrective workload that can be deferred is very small and concerns instruments at the less critical units, which aren't many".

Moreover, despite the fact that the established departmental policy for instrument repairs is not in a written form, people refer to it frequently. The department head added:

"We use the dogma that you can't control a refinery without instruments".

In addition, the department head also talked about the implementation of this policy:

"You realize that we're obligated to develop preventive routines for instruments, such as calibration, or otherwise we wouldn't be able to deal with so many emergencies. [...] Preventive routines can't cope with every problem, since, for example, very often extreme operating conditions outrun the endurance of the instrument".

The head also referred to working practices that reflect departmental capacity to act (Stehr 1992):

"We keep spare instruments for critical refinery processes so when we remove an instrument from its position we replace it temporarily with the spare one. [...] This is a common tactic for many equipment categories, but we're using it extensively for many other cases. [...] We're forced to do so. Some mechanical instruments are repaired within the refinery, whilst some others along with electronic instruments are repaired elsewhere mainly in Greece, and when an equipment piece leaves the refinery for repair you can never be sure about its return".

Finally, the ED head talked about the workload of his department:

"Emergency incidents are something rare in our working life. [...] There's corrective workload but it can be executed at anytime due to multiple redundancies of the installed electrical equipment. [...] We perform preventive maintenance in critical equipment categories in order to avoid the occurrence of emergency incidents. [...] This is also a management tactic that occupies excess personnel".

He also added that:

"Nobody calls the electrical department as long as they have a stable electricity supply".

In addition, a departmental engineer revealed the utilization of the same tactics with the ID, which allows them to plan ahead:

"We often replace pump motors with spares which ensure the uninterrupted operation, then we perform all the required repairs within our workshops, since we have all the necessary skills to manufacture a completely new motor from the beginning".

The department head explained:

"In major shutdowns our work is predetermined and there's adequate time to plan ahead. Our role is mainly supportive of other maintenance departments".

4.9 CMMS and maintenance-related information systems at Petrochem

Having described elements of both the business and the project layer of the case organization, this section provides background to the use of maintenance-related information systems and in particular of Computerized Maintenance Management System (CMMS), since it is an important tool for managing the workload of the PD.

Two independent software applications are in operation within the MD, the CMMS supports the PD and the Computerized Warehouse Maintenance System (CWMS) supports the WD. The first version of a DOS-based application of the CMMS that ran on an AS/400 platform was developed in the early 1990s by a local software house with specifications provided by the PD. Since then, the application has been upgraded twice - the last time in 1996. During the data collection period, the CMMS was utilized by the PD as a stand-alone application for the management of work requests and authorised execution of maintenance works. A PD engineer said:

> "An important use of the existing CMMS is the issue of the daily maintenance schedule. [...] This schedule contains all maintenance works in-progress".

The same engineer also explained that problems with the existing CMMS began with the design phase and continued during the implementation phase:

> "The design was based on specifications provided by our department, which focused mainly on the MWOS, which is a responsibility of the PD. [...] We neglected the development of other aspects such as the preventive maintenance routine database and it isn't only our fault because there wasn't enthusiastic participation from other departments. [...] Consultants cultivated expectations that the CMMS was almighty due to the elimination of the old paper-based system and that this would result to the improvement of the maintenance planning and scheduling function. [...] I believe that at that period we failed to understand the capabilities of the system and of course the tasks required to support the installed system".

He also added:

> "Many functions were neglected or were underdeveloped. [...] Nowadays we discuss the importance of the equipment, the spare parts and the maintenance databases. [...] Developers didn't know their importance at that time, hence little effort was made in order to manage their data. [...] We realized it however when we had difficulties in reporting. [...] (Now) we cannot use the databases for improving maintenance techniques and routines. [...] After the first efforts people abandoned the introduced procedures when they bumped into difficulties in collecting some information. Operators of the OD and the supervisors from the other maintenance departments didn't provide much help. Now the databases contain unreliable data, and some other data have never been registered".

The engineer also said: "Training included only the basics and only few managed to become good users". Furthermore, the other department heads explained that they have never been asked to support the use of the CMMS, and have developed independently preventive maintenance programmes and historical records about equipment performance and failure. The reaction of the ID head is indicative:

> "We have never been asked to provide support or data for the CMMS. All we're asked to do was to complete the Work Request form (for maintenance work). [...] If we had been asked before we

would have made efforts to transfer our records. [...] However, I think that the problem is that from the beginning the CMMS was intended to be used by the PD".

The second software application, the CWMS, was developed in early 1990s simultaneously with the CMMS by a local software house with specifications provided by the WD and with the aim to enable the control and management of the spare parts inventory at the refinery warehouses. The WD head noted:

"The size and the value of the Warehouse impose the use of the application despite existing problems. [...] The most important problems we face in relation to the use of the CWMS concern the lack of user training, the lack of a procedure for registering spare parts, and inaccurate information concerning the remaining stock and its exact location in the Warehouse".

In addition, a WD engineer explained that the CWMS development did not include a number of key functions:

"Attributes such as the database with substitutes for existing spare parts were not developed, in fact we hadn't realized their importance at that stage".

Nowadays, the CWMS is considered outdated and inadequate for maintenance management, as indicated by the WD head:

"The system didn't include any queries for any kind of cross-referencing of warehouse data. [...] Another problem is that for every change we need the developer's support".

Towards the end of the data collection period, the MD attempted to switch to the SAP R/3 application, which is now used in all other Divisions of Petrochem. However this effort, which is still in progress, has so far only resulted in transferring the old databases to the new platform without evident change in the working practices of the MD, according to the PD head.

4.10 Cultural elements of Petrochem and the maintenance division

4.10.1 Cultural elements of Petrochem

A brief article in Petrochem's corporate journal (May 1999) presented the results of a questionnaire survey about corporate culture. The survey, which was conducted by an independent consultancy, concerned only administrative personnel and did not include the Maintenance and the Operations Divisions. In addition, the article did not make any specific reference to the methodology used. This section presents briefly the main points from this article emphasizing those associated with processes of knowledge creation, such as trust, commitment, motivation and explicitly stated values (Nonaka et al. 2001a).

The survey highlighted the existence of two culture articulation and reinforcement mechanisms, the formal statement of organizational values and philosophy, and the design of the working environment (Schein 1985). Thus, Petrochem communicates formally the importance and value of issues related to the satisfaction of customer needs and to the environment, and the value of creating a healthy and safe working area. Moreover, the survey indicated top management's emphasis on the quantity of outcomes produced. However, employees pointed out that the corporate communication system is rather ineffective and therefore they may ignore some corporate policies and targets.

Many employees expressed opinions, either negative or neutral, concerning the issues of personal achievement recognition and rewarding performance levels, both of which are considered factors that influence individual commitment (Blau et al. 1993). Thus, the survey reflected problems related to culture embedding mechanisms associated with the lack of criteria for promotions and motivation (Schein 1985). Indeed, during the current research project, it became clear that many employees were not motivated to invest in their work, since rewards were not proportional to the performance. However, the opinions of upper level administrative personnel about personnel motivation, reward of personal achievements and changes in the company were more modest in comparison to those of personnel in the lower administrative levels. Moreover, women expressed their disappointment about the lack of encouragement of creativeness and equal opportunities. Younger employees were demotivated by personnel distinction according to seniority, especially when it came to issues of rewarding familiarization with the organizational targets. The survey also indicated the existence of low care relationships (Von Krogh 1998) at the upper levels of the hierarchy.

Additionally, two other cultural articulation and reinforcement mechanisms, structure and procedures (Schein 1985) appear to be influential. Hence, the company has a formal structure accompanied by a clear and strict system of regulations and procedures, indicating low propensity for change. Moreover, Petrochem is cautious in adopting new working methods. Technological innovation is the only type of change actively encouraged by top and middle management.

4.10.2 Cultural elements of the maintenance division

In February 2000, the MD participated in a questionnaire survey, known as the Cultural and Satisfaction Survey. The survey included sixty-five questions and the response, despite being optional, had a response rate of approximately eighty-five percent. The survey results were presented to personnel and extensive discussions followed. This section presents conclusions regarding the main cultural elements of MD, as a result of the survey and interviews with maintenance personnel.

The issue of vision and leadership at the MD attracted much interest. Respondents indicated that top management does not provide a clear picture of where the company is heading and low-level employees are particularly affected since they perceive this as a demonstration of low care (Von Krogh 1998) and as a lack of a sincere attempt to understand the employee viewpoint.

In relation to communication issues, employees complained that top and middle management does not keep them informed and does not ensure open information flows between and across organizational levels. In addition, responses provided a sense of rather secretive maintenance organization in terms of decision-making processes.

Moreover, two characteristics of the Greek culture, according to Hofstede (1991), were also indicated: the provision of opportunities for earnings and personal advancement. In general, employees are satisfied with their total benefits package, while three quarters of the respondents answered that their work gives them a sense of personal accomplishment. Another aspect of the Greek culture (Hofstede 1991) that was emphasized concerned the significance of recognition, with low-level employees pointing out that they want top management to demonstrate that they are important to the success of the company. In general, survey participants believe that employee needs and feelings are valued, but there are issues. For example, the lack of a transparent reward system (Schein 1985; Von Krogh 1998) is believed to a lack of reward for creativity and innovation. Furthermore, maintenance personnel described that their work is always overshadowed by others. Hence, for example, they explained in discussions that, while the MD participates in the construction of new units, the laurels always go to the New Projects Division, which officially undertakes projects. Moreover, they complained that since maintenance work is not directly related to the production and the quality of the final product, the OD usually gets the benefits for meeting the production schedule and not the MD, despite keeping the plant in a good condition.

Nevertheless, MD personnel are satisfied with their job, despite the feeling that sometimes they are overworked, and their complaints, expressed during discussions, that work organization could improve substantially with the definition of resource allocation criteria. Moreover, satisfaction came from job security, the emphasis on a safe working environment, and the involvement of Petrochem in issues concerning community.

However, employees of all levels were dissatisfied by the fact that MD does not make good use of their skills and abilities and that it is not very supportive, for example, during discussions it emerged that this problem is not linked to the availability of resources, but to their rather ineffective management.

As far as the culture-embedding mechanism of reaction to critical incidents and departmental or interdepartmental conflicts is concerned (Schein 1985), it was indicated that MD avoids conflicts. In fact, the vast majority of maintenance personnel of all levels believe that MD is tolerant of diversity and non-conformism, demonstrating that groupthink (Janis 1982) is uncommon. Discussions indicated that workforce diversity is promoted by job security and employment procedures that do not allow the strict selection of employees.

The survey also indicated the existence of considerable team autonomy (Mainz et al. 1990; Owens 1991; Daft 1995), since half of the survey respondents said that they are involved in someway in decisions concerning their work. Middle management's answers pointed also to an increased level of independence and an encouragement of teamwork and cooperation, even with suppliers and contractors, with whom employees have very good relations.

In addition, three quarters of the survey respondents claimed that they are positively positioned towards changes, but they think that they have experienced many unsuccessful change attempts in their working environment. Discussions revealed that very often these changes are associated to experimentation (Nonaka et al. 1994; Nonaka and Takeuchi 1995; Leonard 1998) regarding the adoption of new maintenance techniques and methodologies.

Moreover, MD, according to the survey, is only mildly concerned about trade secrets, due to the existing legislative framework, which does not allow the commercial use of patents or other skills and knowledge. In fact, discussions revealed cases of some employees who left the refinery after having worked there for many years, to commercially take advantage of an idea they had come up with during their employment. According to maintenance personnel interviewed, the people who left in order to start their own business had been very successful and stories about them, which function as secondary culture articulation and reinforcement mechanisms (Schein 1985), point to the contribution of Petrochem to their career development.

Another important aspect of the cultural survey concerned the role of systems and procedures as cultural mechanisms (Schein 1985). First, the survey concluded that MD is sometimes a slow pace organization, while at other times urgency prevails with high pressure and stress. An indication of the existence of slow pace is the development of a 9:00-to-5:00 mentality on the part of a significant proportion of the maintenance employees. However, survey respondents said that they believe that requests for maintenance work do get resolved quickly. In contrast, low-level employees emphasized in discussions the time-urgent nature of the organization by narrating the popular and imaginary story of a worker, who has to paint a wall while management pushes him to use more than one brush (see also Appendix Three). Hence, discussions pointed out that MD focuses often on the task on hand and on results, at the expense of process.

In addition, the lack of focus on process within MD becomes clear from another survey question, which highlighted the lack of regular performance reviews. This lack contributes to the conservation of patterns of unequal evaluation and reward of performance, ideas and opinions (Schein 1985). Low-level employees also indicated that the supervisor is the only person to recognize and reward their good performance, but does so subjectively, while the majority of respondents complained that promotions are not based on qualifications and merit.

Additionally, the survey showed that employees consider that the organization's hierarchy has a clear level of differentiation and appreciation to seniority. Respondents also believe that this structure is linked to a large number of contradictory, and often unfair and ineffective rules and procedures that are not explained adequately, something that according to Schein (1985) can cause difficulties to culture articulation and reinforcement. An example of ineffective procedures, according to MD personnel, concerns procedures that impose a centralized system for both control and decision taking, especially for issues concerning budgets. Finally, the survey indicated that the hierarchical structure appears to be an important factor for the impediment of career development, despite existing opportunities for the upgrade of personal skills.

4.11 Summary

This chapter has attempted to present basic aspects of the case organization's business and project layers (Nonaka 1994; Ekstedt et al. 1999). The description of the business layer started with an overview and brief history of Petrochem that highlighted the public character of the organization. The following sections then focused on the company's educational profile, training policy, and existing staffing procedures of the company, and indicated opportunities and problems for the renewal of the organization's business layer. The discussion on the refinery A, the flagship of Petrochem, pointed to its technological complexity. The following sections introduced MD, and its departments, which are the main actors of the maintenance knowledge creation process examined in this thesis, highlighting both the existence of many hierarchical levels that often impede personal development, and the bureaucratic response of the organization to environmental changes.

As far as the maintenance workload is concerned, the chapter focused on its three characteristics: the frequency of maintenance faults that determines opportunities for knowledge acquisition and application, its preventive or reactive nature, and the established departmental policy for its management. All these combine to influence the framing of problems and the provision of working solutions.

The final two sections deal with the organizational knowledge base (Nonaka 1994) and indicate the rather limited utilization of ICT within MD, delineate important cultural elements, pointing to the existence of problems in a number of culture embedding, articulation and reinforcement mechanisms (Schein 1985).

5

The Conditions for Maintenance Knowledge Creation

5.1 Introduction

Having provided, in chapter four, some background for the knowledge creation process by focusing on the business and the project layers of the case organization, this chapter focuses on the general organizational conditions that stimulate interactions within this social process and examines the knowledge vision at the MD as a driving force.

The chapter first considers care (Von Krogh 1998) and trust (Newell et al. 2002) relationships within the MD and presents reasons that commit (Blau et al. 1993; Kalleberg et al. 1996; Price 1997) individuals to the knowledge creation process. We turn then to the issue of autonomy (Mainz et al. 1990; Owens 1991; Daft 1995; Newell et al. 2002) and, in particular, focus on the functioning of autonomous and self-organizing maintenance teams (Varela 1984; Nonaka 1994). The autocratic "navy" culture of the Operations Division (OD) is then described, introducing factors that cause a sense of crisis, or creative chaos (Nonaka 1988a; 1994; Senge 1990b; Leonard 1998). The example of job rotation within the MD is a stepping-stone for insights into the condition of information redundancy (Dretske 1981; Baumard 1999; Von Krogh and Kameny 2002) in the section that follows. The next section presents the dual face - like the two faces of the ancient Roman god Janus - of requisite variety (Ashby 1957; Beer 1985), as a prelude to the final section. In it the equivocal and of ambiguous quality knowledge vision of the MD is considered. In so doing, the chapter provides an insight into the conditions that facilitate and enable knowledge creation in the case company.

5.2 Care, trust, mistrust and commitment at Petrochem

Investigations undertaken as part of this research indicated that there are opportunities for gaining colleagues' trust in one's competence (Newell et al. 2002), takes time and involves socialization interactions. Interviews with an engineer from the RED and another from the OD explained the process of interlinking trust amongst senior and junior engineers. The OD engineer noted the contribution of the existing unofficial mentoring scheme for the building of trust and care relationships:

> "Yes we become friends with the junior engineers and this is natural. It starts with the appointment of a senior engineer as their mentor, but since I have done it many times I can tell you that this process reminds the senior engineer the stress of his first weeks at the refinery. So the demonstration of an interest is natural. [...] We try also to involve them in the everyday problems from the beginning. We do not expose them to very difficult problems from the beginning but we ask for their opinion more and more as time goes-by."

Junior engineers spend a six-month period at the offices acquiring tacit knowledge concerning technical and management maintenance skills before their exposure to the working life of the workshops and the refinery units. This is preparation to gaining the trust of colleagues. A RED engineer explained:

> "The refinery units (the field) are the place where engineers will prove to the supervisors and the technicians that they are skilled, they have the ability to understand the language of the field and assess the quality of the supervisors' and the technicians' work. The first period is like a test, if you pass it then the supervisors and the technicians will trust you. You will become a member of the community."

The OD engineer narrated a ten year-old story, according to which, a junior engineer started visiting the workshops and the units right after he commenced work at the refinery and his inability to prove to the supervisors his technical competence alienated him from the whole department. This engineer did not gain the trust of his co-workers and decided to leave the company after a few months. The OD engineer noted:

> "Ten years after his walk-out from the refinery, supervisors still laugh at him!".

The ED head connected the creation of trust with skill acquisition:

> "An engineer becomes competent when he feels comfortable with his work and he is able to make the right decisions calmly, only then is he likely to gain the trust of his colleagues."

Job rotation also assists the building of trust and care relationships. Interviews revealed that this is of particular importance to low-level employees, who have few credentials. The academic background of an engineer, on the other hand, would allow them to become accepted by middle management almost automatically. During job rotation these employees have the opportunity to gain the trust of their colleagues, including the departmental supervisor. A RED engineer explained that the process of building trust requires the demonstration of technical skills:

> "Unskilled workers have to gain the trust of the supervisor gradually. They have to be trained first. Even skilled workers learn many things from senior technicians, but in such cases they gain the trust of senior technicians and supervisors, during their first projects."

When supervisors select participants in various maintenance teams, trust appears to be an important resource allocation criterion (Schein 1985). Thus, a SED supervisor revealed:

> "Everybody likes working together with his friends, but when we choose technicians for the execution of a work very often we do it based on their skills".

Furthermore, another RED supervisor noted:

> "I respect technicians who come to me and say: "Look I've found something else on the machine, if we don't fix it now it'll break down after a while". This means that he does his job very well. [...] I want such technicians in my team."

However, discussions indicated something that could be verified by examining the Maintenance Staff Database. Hence, the existence of trust relations contributes to unequal skill distribution or skill accumulation to only a limited number of employees. This phenomenon is evident especially in maintenance departments, such as the SED, that employ excess personnel and where the choice of maintenance team members is necessary.

Moreover, the Cultural and Satisfaction Survey also indicated the existence of strong trust relationships amongst employees of each department and between low-level employees and their direct supervisory group. Hence, survey respondents answered that not only do they cooperate with their team colleagues for the completion of maintenance tasks, but also their colleagues support them even in their everyday life problems. In addition, it became clear that supervisors are open, honest, allow personnel to let them know-how they feel, and, as a result, their technicians trust their competence. Supervisors are role models, in that they treat technicians with respect and are considered positive examples for others to follow. A RED supervisor also made explicit that trust relationships stem from their ability to know the challenges that other supervisors face:

> "Yes, there is trust amongst maintenance supervisors; besides they are the only ones who are in a position to realize what I am going through everyday at the refinery!"

In contrast, examples that not only demonstrate lack of trust, but also point to the existence of mistrust amongst some MD personnel groups are also frequent. Thus, the perceived inability of the PD to plan and schedule the refinery maintenance activities is characteristic. The words of the ID head are indicative:

> "The inability of the PD to plan and schedule the maintenance works is a common secret within the Division".

The SED head also noted:

> "After so many unsuccessful planning and scheduling attempts of the PD nobody has the illusion that they will be in a position to do it now, unless the conditions within the MD change rapidly".

A PD engineer confirmed this view:

> "Planners can somehow create a plan, but such plans are rarely applicable".

Hence, MD supervisors plan and schedule, rather than PD personnel. The assistant maintenance manager demonstrated confidence and trust in maintenance supervisors:

> "The PD has never produced an effective schedule. I told you earlier that they have adequate IT skills, however there is lack of understanding about the nature of the work they have to plan. Supervisors of the (other) departments plan and schedule the maintenance work and they are very successful."

Moreover, and despite the fact that the PD head insisted that planning and scheduling problems were due to "lack of adequate training", some interviewees provided other reasons for this, demonstrating the existence of general mistrust of the competencies of the PD. For example, the SED head pointed to difficulties caused by the corrective maintenance workload of their department. The RED head explained that "the PD lacks the understanding of the execution details and of the necessary resources required for the performance of a task", while a SED supervisor highlighted the "distance between the maintenance plan prepared via sophisticated software, and difficulties in its implementation".

In addition with the PD, which is perhaps one of the most extreme cases of demonstration of mistrust, the research indicated other, milder examples of lack of trust. Thus, interactions amongst the departments of the MD, and especially between the departments that execute repairs and the WD are characterized by distrust. The opinion of the SED head about the operation of the WD is indicative:

"Nobody can deny the existence of the problem of spare part registration and identification and its importance in the operation and the organization of the MD. The complexity of the problem is also known and nobody can expect that the warehouse problem can be resolved only with accounting methods. The only certainty is that for as long as this situation is maintained the warehouse personnel won't be in a position to identify the required spare parts for repairs on time."

Moreover, the Cultural and Satisfaction Survey showed that a significant percentage of respondents consider that the relationships of personnel with top management are not so satisfactory, since personnel do not always trust their managerial skills. Low-level employees were of the view that this is connected to the fact that top management is not very sensitive to the impact of its decisions, especially in issues having to do with the firm's future. For example, a SED supervisor complained about top management's actions:

"Yes there is this notion amongst low level personnel that once engineers move to the higher levels of the hierarchy they tend to forget their previous life at the workshops. This opinion is maintained by top management's decisions and announcements that seem "extra-terrestrial" and make us wonder whether they retain contact with the local reality, or it is the expression of over-ambitious estimates."

In addition, distrust and suspicion exist amongst middle and lower management. A RED engineer highlighted the free movement of the supervisors between the workshops and the units as a source of uncertainty:

"Engineers know that they cannot have blind trust to supervisors. It's very easy for supervisors to provide a justified explanation for their actions, since they move constantly and can always provide you with excuses. Engineers should be at least a little bit suspicious of their actions."

Perhaps middle management sense distrust from low-level employees as well, since interviews with department heads and engineers revealed their desire to protect their trust relationships with their colleagues. For this reason, middle management blame the introduction of ambitious goals on the demanding requests for maintenance works made by the OD. The ID head said:

"This is a managing trick, which allows you to give strict orders without your subordinates hating you".

However, the rather excessive use of this "managing trick" in order to boost maintenance works appears to have an unintended impact, since it creates mistrust between the OD and the MD. The PD head noted:

"None of the maintenance employees believes that the OD makes some sort of attempt to understand possible problems in the execution of maintenance works. The OD puts pressure on us to complete the job as soon as possible. [...] We understand that they have to operate their units, but neither do they trust our job prioritization, nor do we trust them, when they demand the urgent execution of a maintenance job, we ask, is this job really an emergency".

The same department head also pointed out the reduced interactions between the two divisions by explaining that the OD does not contribute significantly to the scheduling of maintenance works and that no maintenance and operations scheduling meetings take place. A PD engineer explained the climate of interactions between the two Divisions:

"Operators keep requesting the execution of maintenance works, very often without raising an official Work Request. When they do raise a Work Request, they keep phoning their engineers and our department heads in order to put pressure on us. My colleagues can give you examples of being threatened by operators to perform even the most trivial tasks! What's most disappointing is that they rarely recognise the fact that the laurels of the OD (which manages to meet and exceed specified production targets) are given for the quality of our work that allows equipment to operate efficiently. [...] It's very difficult for me to recall even just one repair in which we did our best to complete it, and operators recognised the effort."

Besides the plurality of evidence about trust within the MD, the research demonstrated the existence of both low and high care relationships (Von Krogh 1998). In general, many interviewees of all levels attempted to describe the existence of an atmosphere that fosters care relationships and companionship. An example of empathy and companionship as a corporate value (Von Krogh 1998) was recorded in the Research Diary. One day, during the execution of maintenance works, the insulation of a vessel was accidentally set on fire causing one of the most critical alarms within the refinery. However, both the technical director and the maintenance manager ran to the unit, neglecting the relevant procedure. Some days later in an informal discussion, the maintenance manager talked about his reaction to this critical incident:

"When you care about your workers you have to show it when they're in danger. [...] We didn't go there because we were responsible - in such cases the relevant departmental engineer and the supervisor bear the responsibility. We went there because we wanted to provide help and advice."

Another example of care was provided by the SED head during a discussion:

"Before the (1987) refinery extension we had frequent problems with snakes, which used to come in from the near-by swamp. They preferred to stay under the warm pipes in order to hibernate. I remember that I used to check underneath the pipes before I'd allow my crews to work in the area, because I wanted to ensure that they would be safe."

Examples of lenient judgement (Von Krogh 1998) are also frequent. Indicatively, during discussions, supervisors covered their colleagues for making inaccurate fault identifications. A SED supervisor said:

"Even very experienced colleagues make mistakes in fault identification, but what should we do about this? We don't crucify them. Everybody knows that fault identification is a game of possibilities."

An ED engineer agreed that for many decades employees had the feeling that working for the refinery was like running "a family business", but noted that this had gradually changed:

"To tell the truth the family feeling has changed. First, the refinery grew with the addition of new units and the employment of many people. Suddenly, the refinery had twice as many employees as it had before the revamp. But the family feeling has changed dramatically during the past 2-3 years after Petrochem joined the stock market. The uncertainty surrounding the privatisation has also spoilt the environment. And the expansion of the Group with the acquisition of many other companies in a very short period of time changed the family feeling, despite the fact that the executive board very often refer to the Group in press articles by saying "the Petrochem's Family". It's not the same."

The maintenance manager had a different view, however:

"We've been working at the refinery for many years and this has created this (family) environment. Everybody has the feeling that we are a family. Top management has also nurtured this feeling by catering for various employee needs".

But other observers tended to question the sincerity of this opinion. A senior consultant, who was involved in a corporate project, doubted:

"I don't think they're a family, because there isn't any control. In families there's control. Parents control the children. In families criticism is also accepted because you know that others propose something for your own good. [Here], there are signs of frequent disrespect of colleagues. And not many have the courage to take on responsibilities. This isn't empowerment, because in order to empower somebody you have to recognize that the issue is your responsibility and you allow him to take the decision for you. [...] The old fashioned way of their operation reflects introversion that creates power kingdoms that are maintained by the encryption of information and technical knowledge."

But again, this argument was answered by all. An engineer from the SED said:

"There aren't any power kingdoms in the Division. We have specialist jobs. We're willing to share information provided that we have someone who understands us. [...] We explain to others What, How and Why. We don't keep knowledge."

In addition, the Cultural and Satisfaction Survey highlighted the existence of low care interdepartmental and interdivisional relationships, which are characterized by competition and power struggles at top and middle management levels. The survey indicated that for low-level employees, these management levels are not always successful role models (Schein 1985). A supervisor said during discussions:

> "Career prospects for engineers are always open and this justifies a degree of competitiveness. If you're a supervisor, you know that there's no further career progression."

Nevertheless, power struggles at the top and middle levels are not the norm, since interviews pointed out relationships that bond members of each hierarchical level irrespective of their department. For example, an ID engineer noted the existence of companionship amongst middle managers that stems from their common engineering identity (Wegner 1998):

> "There is solidarity not only amongst the maintenance engineers, but also amongst all refinery engineers. There are some things that bond us together. For example, the employee union does not represent us and this has unified us many times, in order to promote our interests to top management. [...] Yes, I think there is trust amongst maintenance engineers, they're considered as comrades."

Besides professional relations, personal relations within groups, according to the same survey, appear to be harmonious, while trust ensures the lack of significant cooperation problems. Moreover, interviews indicated the building of care and trust relationships among the maintenance personnel, the external contractors and the equipment manufacturers. A RED engineer said:

> "The problem with the small Greek market and the difficulty in finding specialized technical skills is a given. So if you train a contractor to maintain your equipment in the way you want there's no reason to destroy the relationship. Not only because they're likely to return for work at the refinery, but also if you ask them to do more, they never refuse. [...] You can understand why there're contractors, who have permanently reserved spaces for their personnel, since I started here."

Interesting observations were also provided about commitment within the MD, since the investigation reflected the existence of a wide spectrum of factors that commit (or do not) individuals (Blau et al. 1993; Kalleberg et al. 1996). First, committed middle managers are often involved in knowledge-creating initiatives. An ED engineer noted:

> "Basically when personnel volunteer to undertake a project it's because of their craving for their job. Promotions and financial rewards aren't connected to productivity. It has nothing to do with the money."

The ED engineer explained that these individuals move freely from one role to another and, as a result, they are exposed to new knowledge and ideas:

> "We try to be informed about state-of-the-art developments. If we find something that looks interesting and we think that it may have a potential application, we investigate it further. [...] I

travel abroad once every two years. There are other colleagues who travel more often. We have the opportunity to examine the technology closely, to discuss with people about its difficulties and its benefits. In order to propose to the department or to the MD the introduction of something new, you have to be convinced about its value."

Hence, middle management's commitment enabled not only the development of the refinery substation network with autonomous electricity production units, but also allowed the creation of knowledge about equipment operation with the application of a condition monitoring system and the introduction of innovative maintenance techniques, such as laser alignment at the beginning of the 1980s. The ED head talked about the substation network:

"Our engineers had seen broadly developed substation networks in US refineries. However, the idea was initially considered as a luxury - a waste of money. It was only after the 1988 (nationwide) blackout, that they (engineers) introduced this idea again."

In addition, a RED engineer pointed out middle management's commitment to technological innovation:

"We operate a refinery with an index factor for established technology of eleven when the average refinery index factor within the EU is seven and a half, while more than half refineries hardly reach this average. [...] We're committed to technological developments or else we'll miss the train. [...] Well when I say the train I mean that if you rest on your laurels, you wake up and discover that your company has a number of safety and reliability problems that can't be fixed from one day to the next. With our attitude we don't allow this to happen and this is evident if you consider that we haven't had a fatal accident for more than fifteen years."

Besides middle management's commitment, there are also frequent examples of lower management's commitment that have resulted in substantial improvements. For example, a RED supervisor narrated the following story:

"We had a colleague, a supervisor from the SED, who upgraded the entire pipe network of the refinery within a decade. [...] Very often the production unit and the storage tank are located at a distance from one another, which sometimes can be quite a few kilometres. The problem was that specific pipes used to lead to specific tanks and when we had problems with the feeding pumps this could block the entire production. The supervisor took some surplus pipes from a completed project and started constructing, on his own initiative, "smart" piping interconnections that allowed the by-passing of pipes with leakages or broken pumps, enabling speedy repairs. [...] The funny thing is that when he left the refinery his son continued his work. [...] Nowadays we are in a position to transfer any (product) quantity from any unit to any storage tank even if half of the feeding pumps are broken."

Additionally, and in separate interviews, both the ID and the ED supervisors explained that an important commitment factor within the refinery is the national importance and the social responsibility of Petrochem's refinery (Kalleberg et al. 1996). The ID supervisor said:

> "Yes, the national importance of the company commits us. We know that we work in a public organization and we control and manage public funds. This is also a responsibility."

The ED supervisor concurred:

> "I think that everybody is more or less proud when they find out the importance of the company. [...] Even the army also guards this place."

However, the Cultural and Satisfaction Survey indicated the existence of the other face of commitment within the refinery, reflecting the public character of the company. A significant percentage of employees, mainly from lower levels, exhibited a "nine-to-five" mentality and demonstrated openly that their motivation and commitment is connected to basic rewards, such as income (Blau et al. 1993; May et al. 2002), and not with the promotion of knowledge sharing and creation or some other organizational value (Kalleberg et al. 1996). A PD engineer noted:

> "Motivation is something difficult here. The only motive is whether the supervisor will allow technicians to work overtime."

The SED head also pointed out the role of supervisors in fostering commitment among low-level employees:

> "In the absence of an established official incentive system the only way to motivate technicians is to allow them to work overtime. Other times supervisors allow technicians to leave earlier in order to take care of personal needs. The supervisors propose to engineers and department heads promotions and salary increases. Of course, these proposals aren't always accepted, but in general, I believe that people who work hard or more than the others get some sort of reward."

The same head also explained:

> "There is not an established official system that will define rewards according to objective criteria. You realize that there's a possibility that people from other departments who may work less than my technicians might get a higher salary. I'm trying to treat my personnel as objectively as I can, but the system allows unequal treatment or even discrimination amongst the employees."

Furthermore, an ED engineer said that employee commitment is sometimes "loose" at the technologist's and the senior technician's levels, because of the existing structural and legislative barriers, which impede personal development:

> "It's true that people at the technologist and senior technician levels are often demotivated by the fact that they don't have any promotion prospects."

The Cultural and Satisfaction Survey indicated the existence of additional reasons that influence commitment. During discussions concerning the outcome of the survey, a supervisor said:

> "Job security is a great relief in contrast to other organizations. You can work without having to think all the time that in case of an unfortunate decision you'll have to leave".

A RED engineer also mentioned during the same discussions:

> "When most of the employees don't know the corporate vision, and those who do know it don't communicate it, what sort of coordination and commitment would you expect? Commitment is limited mainly within the departmental objectives and boundaries."

5.3 Autonomy

The links of the hierarchical structure of the MD to legislative requirements not only impede the personal development of technologists and senior technicians, who are often leaders of maintenance teams, but also obstruct their autonomy. An ED technologist explained:

> "Every decision we make has to be approved by an engineer. An engineer is involved even in the most trivial working details".

These barriers have prevented the organization from creating cross-functional autonomous teams. A RED engineer said:

> "It's very distracting for us to monitor and approve the actions of technologists, especially because we know that these colleagues are competent, but there's no other way. [...] This is the reason why we had to reject the creation of cross-functional teams when consultants suggested this in 1992 (during the last restructuring effort). [...] Consultants had also suggested reducing hierarchical levels and we rejected it for the same reason. Labour legislation imposes the existence of so many levels and has also formed the internal regulation of the Division."

An ID engineer added:

> "Even a chartered engineer is not allowed to supervise workers from other disciplines. Therefore while we can create a cross-functional team, but we cannot find an appropriate team leader".

Additionally, legislation also bars autonomous action, since it limits financial decisions. The SED head noted:

> "In Greek public organizations department heads have limited authority over budgets. Only the Divisional Manager can approve budgets without restriction."

Nevertheless, middle management personnel do act autonomously. The case of the SED provides an example. Their departmental activities are divided into two major sectors managed by two chartered engineers. According to the official organizational chart, the senior engineer supervises the other engineer, despite the latter having approximately ten to eleven years' experience and despite the fact that their activities - supervision of welding crews and supervision of other technicians - are completely different in nature. The department head noted:

> "The two engineers discuss and cooperate frequently, but the senior engineer cannot control the quality of work of the other engineer. In fact neither can I supervise him. [...] He's empowered to manage his group. [...] At this management level there aren't any legal implications for this empowerment. The two departmental engineers are university graduates with the same educational and professional qualifications."

Similarly, another example outside the MD concerns the case of the head of the Training Department, who explained:

> "In the late 1980s I realized that the refinery lacked an organized training department. Every refinery I had visited in Europe had such a department. [...] I was an engineer in the Process Division when I proposed the idea (to top management). They agreed and they assigned me the responsibility to organize the Department. [...] As I've told you, nowadays our department organizes and manages approximately two hundred seminars and a few dozen educational trips yearly."

The Training Department example indicates that employees within Petrochem who come up with an attractive idea are allowed to investigate it further. Hence, the MD personnel are encouraged and given the autonomy to experiment on a broad spectrum of activities. The ED head noted:

> "There's an atmosphere that favours experimentation. [...] Yes, it's a cultural aspect of the Division. [...] Personnel who participate in the construction of new units are used to the performance of mandatory operational tests before the normal operation. They cultivated this atmosphere of experimentation in the department and others followed them. [...] Employees who want to investigate their ideas on the construction and operation of experimental mechanisms and systems are always encouraged."

Moreover, the ID head explained that such experimentations are performed by all departmental employees and noted their benefits:

> "Experimentations of departmental employees often result in the discovery of cases of poor instruments' functionality, which are being reported to the instruments manufacturer. [...] Very often with the results of these experimentations we modify instructions on how to use the instrument."

Notwithstanding, and besides autonomous experimentation, interviews with the heads of the SED and the RED indicated difficulties when it came to autonomous action and empowerment of employees below the engineer's level and the possibility of the creation of a flatter organization. The RED head explained that supervisors lack typical professional qualifications and therefore they are not formally authorised to act autonomously:

> "In case of an accident within a team, the responsibility is transferred to the engineer and not to the supervisor. The supervisor has some responsibility when he's a graduate of at least a polytechnic school and this happens only in other Departments (such as the ID)".

The SED head referring to this issue said:

> "I know that these problems are resolved in other EU countries, but not in Greece, and there's no indication that they would change in the future. [...] There's lack of political intention by governments when it comes to dealing with professional rights issues."

However, and despite the indications of the inflexible barriers for the operation of autonomous teams, the existence of such teams that operate under the leadership of the supervisors is an undisputable fact. Both department heads and engineers were very hesitant to admit in interviews that, despite official regulations, supervisors did very often act autonomously. An OD engineer noted that a decisive factor for the establishment of the existing status quo was the power of knowledge:

> "All supervisors within the refinery have on average ten years' experience more than the engineers. When you are new at the refinery you have no other option but to trust them. Otherwise you'll not be able to control them one day [...] Yes, trusting them means allowing them to do what they want, at least sometimes. [...] Besides they're more experienced than everybody else in here."

In addition, an ED engineer admitted that supervisors, by using their knowledge, acquired a kind of silent acquiescence by the engineers for their actions.

Nevertheless, the supervisor's group has a substantially different view of the autonomous operation of their teams. The response of a RED supervisor is indicative:

> "We have created a system with autonomous teams that operates irrespective of the changes and decisions at top management level that often fragment the maintenance organization".

Additionally, the SED head denied that supervisors pull the strings at the refinery:

> "Supervisors have an increased level of autonomy in everyday tasks because they have gained the engineers' trust that they will complete their tasks successfully. [...] Supervisors are also competent at controlling their crews. They know their teams and the skills of their technicians very well and they know how to motivate them."

Hence, supervisors and their crews often work autonomously, but their teams are not cross-functional. The ID head noted:

> "Supervisors manage teams consisting of only members from departmental crews."

According to the Cultural and Satisfaction Survey, autonomous supervisors encourage teamwork and promote cooperation between various teams and groups. The ID head, using the example of maintenance tasks that require many different trades for their execution, explained that supervisors reduce the repair time, since they ensure unrestricted access to information for all team members:

> "Well, supervisors communicate with their colleagues from other departments and very often resolve issues before we realize their existence."

Moreover, the Cultural and Satisfaction Survey indicated that the unofficial, quasi-autonomous and self-organized low-level maintenance teams have decision-making autonomy (Mainz et al. 1990; Owens 1991; Daft 1995), since two thirds of the technicians decide on the team's actions with the supervisor's guidance. The survey also pointed out that low-level employees consider it as a problem that they are not officially empowered to correct problems as they occur, due to existing legislation.

In addition, the maintenance supervisors, with the exception of supervisors from the PD, highlighted in interviews their autonomy to select the members of maintenance teams. The response of a RED supervisor was indicative:

> "Depending on the work, we select the technicians. Sometimes senior technicians are also involved in this, but normally this choice is ours. [...] We do this for a variety of reasons, either in order to train somebody or because we need specific skills."

However, these autonomous teams vary significantly. A cross-reference of data from the Maintenance Staff Database with interviews indicated the importance of factors such as team size and supervisors' educational background. Hence, the departments of the ED and the ID have better educated supervisors, who are polytechnic graduates, and relatively small autonomous teams, in contrast to the SED and the RED. A supervisor from the SED said:

> "Yes, our teams are large, sometimes they reach ten or fifteen people. [...] This happens not only because we employ excess personnel, but because of the nature of our work, as we need speed. [...] For example when you have to assemble five hundred meters of pipes, you need a large team."

Conversely, the head of the ID explained:

> "Our teams consist of three to four people. [...] All our supervisors are polytechnic graduates because they usually deal with high-tech equipment. [...] We don't employ excess personnel, we manage our workload just fine."

The same head added:

"The use of polytechnic graduates as supervisors is advantageous. [...] We can communicate more effectively and produce high-quality outcomes."

Although, the majority of the PD employees are graduates of the higher educational institutions, teams are not well supported with planners. The PD head explained:

"If you consider the size of the MD and the average workload, the PD is probably understaffed."

5.4 Chaos creation in the MD or the navy culture of the operations division

The interactions of the MD with their customers, the OD, are constantly and artificially stimulated by the so-called "navy culture" of the OD, which evokes a sense of crisis. The ID head explained that seventy percent of the middle- and low-level employees of the OD have either served for some years in the Greek navy or have been trained in the technical school of the commercial navy:

"The navy culture exists (within Petrochem) and it's autocratic. Seventy percent of the Operations' workers were mechanics in the Greek Navy. They are used to giving orders, which should be followed blindly by others."

An OD engineer added:

"Well, nobody wants to remain a mechanic in the navy especially when he has a family. Sooner or later he starts looking for a job on land."

The ID head explained why so many commercial navy mechanics were employed:

"Oil refineries were the most appropriate choice for them since they are equipped with more or less the same equipment, such as pumps, compressors etc, as ships."

However, the head highlighted a basic operating difference between oil refineries and ships:

"Ships have limited space and consequently they don't have spare equipment installed. In ships, machine operators give direct and autocratic orders about what has to be done and by when. You realize that there's a great hazard for the ship to remain ungoverned if something breaks down. [...] Here, things are different because installed spare equipment reduces the impact of failure."

This navy culture is maintained, since top management demonstrates solid trust in the skills of the OD and frequently makes statements about the contribution of this division to the corporate success thereby reinforcing the existing culture. A RED supervisor noted:

"There is a feeling in the MD that refinery management is extremely comfortable with all the decisions of the machine operators. Besides, experience has shown that for the past ten years they meet and exceed all production targets. Management takes for granted that operators' decisions are correct and one reason is the belief that graduates of Greek naval schools are very competent. [...]

> Yes, there is blind trust in the OD, which does not leave much space for questions about their behaviour when they request the execution of any kind of work."

Indicatively, a RED engineer also added:

> "Irrespective of the importance and the severity of the problem, the operators demand an urgent response from the maintenance personnel as soon as they request something!"

In addition, a SED supervisor pointed out:

> "Operators' requests are very pressing, while they provide little explanation."

However, the existence of the pressing navy culture of the OD itself would never evoke a sense of crisis, if the MD would not allow this to happen. Hence, the absence of unambiguous criteria for the identification of the criticality of equipment faults and for the prioritization of work, gives ground to pressing requests for maintenance work. A RED engineer noted:

> "In fact, real emergency incidents are quite rare due to installed spare equipment, but this has upgraded other not so urgent works to the most urgent category of maintenance works."

Additionally, the ID head said:

> "This culture of the OD often causes problems to the organization of maintenance works, but I don't think that the OD would ever accept the prioritization of maintenance works according to predefined criteria."

Furthermore, this navy culture is extensively used by MD middle management as an excuse for imposing tight job execution schedules and facilitating various issues. A statement by the ID head is revealing:

> "I can't deny that we do use the "navy culture", and the myth that was created around this idea was intentional. [...] Not only in my department, but also in other departments, engineers and department heads use it. [...] Well, when I say myth, I don't mean that it's completely fictional, we just overemphasized some aspects of the culture in order to take advantage of it. [...] This situation with the navy culture is very old. It was old when I came to the refinery."

Hence, the navy-culture is utilized to meet challenges. A RED engineer explained:

> "Sometimes they (maintenance personnel) are intimidated that in case they fail to demonstrate the required results operators will complain to top management, and this has happened in the past many times. On the other hand they know that participation (in repairs) ensures opportunities for working overtime and this is the bait. [...] You know there are technicians who get a second salary due to overtime payment."

The RED head said:

"Only by saying to the repair team that a department head called you to complain about a delay can you speed up the work at least thirty percent!"

A SED engineer noted:

"We can make technicians work overtime or we can get the authorization for the execution of a job within a day or an hour."

A supervisor from the same department added:

"We have built entire pipe networks within a few weeks."

Similarly, an ED engineer noted:

"We put pressure on our technicians especially when they participate in the construction of new units, and usually they complete the project on time."

However, such time urgency is often associated with a "just get it done" environment that was indicated both by the Cultural and Satisfaction Survey and by a PD supervisor:

"Sometimes the navy culture is an excuse because if we by-pass procedures, we finish the job earlier."

Hence, MD management achieve results with the use of the navy culture, but actually the energy and the motivation of interactions in this situation are extrinsic. Meeting notes from group discussions with middle and lower management revealed that employees agree that mainly the "customers" set objectives, whilst the MD takes advantage of the culture only marginally. The RED head agreed:

"Yes, the objectives are set by the OD, but along with a group of their objectives we promote our own interests as well. [...] If you attempt to make technicians work harder they stick to a nine to five mentality and they argue that they already work hard enough. Other ways of motivation are difficult since the system is rigid."

A senior consultant explained that the use of the navy culture shows that the MD is sensitive to criticism and added:

"How can they improve if they don't question their present situation? This, of course, is an indirect consequence of not examining every action under the cost-benefit prism, with environmental, safety, financial or other criteria. They also reject cost-benefit analysis, since it raises questions for their actions."

Additionally, there is limited use made of tools that motivate and initiate criticism, such as performance indicators. The assistant maintenance manager said:

"No, there is no established divisional-wide use of performance indicators. Some departments, such as Electrical, have established their own indicators, but only for departmental use."

During discussions a RED engineer noted:

> "A performance indicator system would also be ineffective in personnel motivation. Everybody would treat it with suspicion."

In addition, discussions revealed that the MD is not very familiar with other problem solving methods - other than brainstorming - that could enable not only the framing and the resolution of problems, but also the questioning and the re-evaluation of adopted practices. Therefore management is deprived of a number of tools and methodologies, which could allow it to read the current situation and stimulate interactions by introducing intrinsically a sense of crisis.

Moreover, and besides the navy culture, the unequal personnel distribution within the MD and the current employment system are additional, but not so decisive reasons for imposing ambitious objectives. A SED supervisor explained:

> "Despite the fact that normally we employ excess personnel we've experienced cases in which the task at hand required more resources than existing, while, by coincidence, external contractors weren't available. What can you do then? When you are with your back to the wall all you can do is to push them to work harder. [...] Only in such difficult cases is it possible to enforce a strict policy."

Moreover, an ID engineer pointed out that such situations promote external knowledge transfer:

> "When you know that the employment system requires sometimes up to a year for the completion of the procedure in order to get a new worker with specific skills, the most preferable choice is to train an existing worker. It's much easier and we don't leave them much space to refuse. [...] Yes, such crisis situations provide an excellent opportunity for the approval of budgets concerning additional skills."

5.5 Information redundancy at Petrochem

In the absence of a fully developed job description system and a standardised training programme, job rotation has traditionally been the main way not only for the intentional overlapping of information and knowledge about business activities and assigned responsibilities within Petrochem and its MD, but also for transferring skills. The PD head said:

> "The Division had never had a fully developed job description set. People are usually informed about their responsibilities by internal regulation and by current legislation."

The investigation identified two complementary kinds of job rotation within the company. An ID engineer explained that the first type of job rotation is "the unofficial way to train new employees about the refinery by spending a couple of years within two or three different departments and divisions before the identification of his final position". The same engineer added:

> "Engineers usually spend much more time in various divisions before the selection of their position than technicians, who don't usually spend more than a year in other departments."

Meeting notes from discussions with middle and lower management during the training seminars reveal the importance of this type of job rotation for employees. A RED engineer said:

> "Everybody makes friends within each Division he enters".

Another engineer pointed out:

> "You can never be sure about the connections of an employee with other departments, but you can always be sure that there are not only friendships, but also alliances."

A supervisor noted:

> "In case of emergencies everybody contacts his friends in other departments. Everybody does it. They give you accurate information without having to wait!"

The ID head indicated another benefit of this kind of job rotation:

> "It's self evident that when somebody has spent a few months in other Divisions, he can better understand his role within the MD."

In an interview, the assistant maintenance manager explained that the role of job rotation goes beyond the achievement of control (Nonaka 1994):

> "It's not only the fact that employees understand their role within the Division or that they comply with departmental objectives. The most important factor is that we are doing this (job rotation) in order to find the right position for each one in the refinery. [...] We have to find a position suitable for individual skills."

Traditionally, all refinery engineers before joining the OD spend some time in the Process Division, where they have adequate time to familiarize themselves with the refining process that they will manage in the OD. The assistant maintenance manager explained that:

> "It's easier for an engineer to understand the environment of the refinery in the Process Division before moving to the OD. But anyway, we have transfers in all directions [...] Transfers between the Operations and the MDs do happen, but not frequently."

However, this type of job rotation is not standardised. The assistant maintenance manager said:

> "There aren't standard criteria for the rotation of employees, either the employee may request his transfer or management may decide that he could improve his skills somewhere else."

Furthermore, meeting notes from discussions with middle and lower management indicate the influencing role of supervisors on this type of job rotation. A PD engineer pointed out:

> "I know cases of people, amongst them engineers, who went to other Divisions just because the supervisors had proposed it!"

The identification of a suitable maintenance department for the employee initiates the second type of job rotation, which introduces him to the various teams of this department and allows him to accumulate tacit knowledge from demonstrations by senior technicians or senior engineers. The PD head explained: "All maintenance departments organize (internal) job rotation programmes", while the ID head added: "All employees, irrespective of their level, participate in such internal job rotation programmes, since there's lack of a structured training scheme, despite the efforts made. [...] We cover training needs with job rotation, and this depends on the decisions of each department head". A RED engineer added:

> "The employee during his apprenticeship in the various teams of the department in which he belongs meets with all of his team-members."

Interviews confirmed the importance of intra-departmental and non-standardized job rotation. Thus, the SED head noted:

> "The employee acquires necessary experience. Only then will he be able to participate in the activities of the crew."

The assistant maintenance manager pointed out:

> "The employee understands the basic activities of the department and realizes the object of the maintenance work and gains experience."

Furthermore, a SED supervisor connected job rotation with the building of trust:

> "This job rotation process often turns out to be demanding since the employee goes through repeated tests, until management is convinced that the employee is adequately trained."

He went on to describe the job rotation process:

> "We take the newcomer and despite the fact that we have in mind that he will join a particular crew, we send him to participate in the activities of all other crews of the department. [...] Sometimes he stays with each crew for a few weeks or he joins his normal crew and supervisors send him to observe activities that might be of some interest."

The ED head described how middle management participates in job rotation:

> "Senior engineers take the engineer out in the field to monitor the execution of various departmental activities".

Moreover, the PD head pointed out the supervisors' role within this skill and knowledge acquisition process:

> "Supervisors play a key role in this process. They examine the qualifications of the newcomer and propose to the engineers what he needs to learn based on the existing refinery needs. [...] Department heads and engineers usually follow the supervisor's proposals."

The assistant maintenance manager pointed out a weakness in this job rotation system, but concurrently supported it:

> "On the bottom line, it may be rather expensive and time-consuming, but job rotation produces competent workers and technicians. We are very satisfied with the average employee's level of competence."

Moreover, a PD engineer added: "This training method generates unequally skilled maintenance personnel", while the ID head noted as well: "The existing system is rather one-sided since it does not provide equal opportunities for development".

Notwithstanding, opportunities for the acquisition of redundant information by employees become fewer following the two job rotation programmes. The ID head said:

> "When the employee completes his training he remains in his position in which he specializes and further transfers are rare."

However, and in contrast to low-level employees, job rotation opportunities for middle managers still remain. The ED head explained the motivational role of job rotation for engineers:

> "It's possible that engineers can be transferred to another department either temporarily or permanently (after many years of employment at the same department). [...] This happens only with top management's authorization and usually these people have either requested or approved of their transfers. Top management sees it as a chance to attract the interest of people who have been working here for many years."

Interviews indicated that, besides job rotation, alternative opportunities for the acquisition of redundant information are rather limited. Such an opportunity concerned a role simulation exercise that occurred at the ED. In an interview the department head explained that engineers interpreted top management's directives for increased safety and introduced exercises that simulate failures of the refinery electrical network:

> "We started these kind of exercises about ten years ago. There were lots of conversations about taking precautions against the hazards from large (failure) incidents. So we (middle management)

proposed these kinds of safety exercises. [...] We're trying to prepare our personnel. These failure scenarios simulate incidents that are very likely to happen. [...] Well, participation concerns mainly departmental personnel. [...] The purpose is to prepare them to respond in case of incidents that cause unequal distribution of electric load. [...] We do one major exercise once a year."

This kind of role simulation exercise, which does not involve IT simulation applications, not only promotes information redundancy, but also prepares personnel for their roles. The head added:

"The exercise tests the readiness of personnel to play their roles during the incident. Everybody has an agreed position and a specific role."

Finally, the head noted the protagonist role of middle management in this exercise:

"The engineers are responsible for the whole set up of the exercise. [...] During the exercise they check if everybody knows their position, how they perform their role, and if there's room for improvement."

Besides this infrequent opportunity for the acquisition of redundant information, the ID engineer noted that middle management often attend seminars and conferences. A PD engineer explained:

"We receive sporadic training in the form of seminars in Greece or abroad concerning maintenance techniques and methodologies that help us perform our jobs, and nothing more than this."

The PD head also mentioned:

"Middle managers have the autonomy to choose when and how they will update their knowledge with seminars and conferences."

According to the PD head, top management encourages participation in such events, since many times, knowledge from seminars was adapted to local conditions. The ED head explained:

"Departmental personnel often attend courses and informative workshops. [...] One of the achievements of this department is that, based on material provided by manufacturers and suppliers, we've managed to adjust and extend it for the benefit of our refinery. [...] But this requires very good familiarity with the manufacturer's instructions before we move one step further and attempt to change them."

Finally, the PD engineer explained that the company-wide use of Lotus Notes, which the supplier argued could support "the sharing of non-codified and tacit knowledge of the organization", does not promote the sharing of redundant information within the MD:

"The application was first installed at Petrochem seven years ago. [...] Since then we upgraded it twice. [...] Petrochem bought users licenses for all employees and it is the only email application we use. [...] We didn't receive any particular training for its use. [...] Besides the management of email accounts and the posting of the refinery telephone catalogue, this application has never been used for anything else."

5.6 Requisite variety

As far as the realization of requisite variety within the MD is concerned, the investigation unveiled some contradictions. While there are numerous opportunities for an employee "to combine information differently, flexibly, and quickly", the issue of "equal access to information throughout the organization" (Nonaka et al. 2001) seems utopian.

The unofficial and non-standardised job rotation scheme, which may last up to two years, contributes to the achievement of a certain level of organizational integration. An ID engineer noted the development of a common understanding:

> "Every employee within the refinery is in a position to understand the functions of other departments and divisions after job rotation."

In addition, the PD head explained that socialization during job rotation creates communication channels:

> "Personal friendships play an important role for the communication of information. [...] I can say that communication within each department is good, but friendships ensure communication beyond the department (interdepartmentally and interdivisionally). [...] Yes, job rotation is an important factor (for these friendships)."

However, and besides job rotation, there are other requisite variety enhancing opportunities that continue throughout the working life of maintenance employees. These allow them to deal with the complexity of the environment and to explore their abilities to combine information and knowledge in new, flexible ways. Thus, one characteristic opportunity is the participation of maintenance personnel in the construction of new units and their involvement in all non-maintenance related activities, such as unit modifications. An OD engineer explained that this participation is requested by production people who, in contrast to low-level equipment operators, believe that the "MD personnel will do a good job and will control the contractors who aren't familiar with the specialties of the local operating conditions". The same engineer also said:

> "We don't expect that external contractors will take care of our equipment, better than our own people. We trust the maintenance personnel since unit operators risk their lives every day in a plant with high pressures and temperatures, and in which explosions are very possible."

The ED head provided another perspective:

> "(Top) management is generally supportive of this, though silently. They know the situation but our involvement reduces costs and provides a solution to keep people busy."

In response to this need the ED has created a crew fully dedicated to new construction, "The New Installations Crew", with all other departments providing resources on an as-needed basis. The head also explained that since electrical equipment is very reliable and in general requires limited maintenance, the constant involvement of the department in constructions is "a permanently open door for the acquisition of new knowledge and skills".

The same department head pointed out the significance of technological discontinuities (Tushman and Anderson 1986) during the construction of new units for the embracement of diversity and organizational combinative capabilities (Kogut and Zander 1992) by his personnel:

> "We're involved in the construction of a new electrical unit every three to four years [...] Yes, there is a substantial technological difference between each unit generation. [...] The new installations team is involved in the project, but after the construction's completion the rest of the employees are obligated to learn how to maintain the new unit. [...] Personnel see such constructions as a challenge that breaks the monotony of everyday routine. Personnel are required to find out the (operating and maintenance) differences with the older units. The operators and the other departmental crews are longing to do this. [...] By pushing them to cope with new technology we also maintain their interest to keep up with current professional changes. Keeping up with these advances is in the culture of our department."

The same interviewee explained that the operation of electrical units provides an additional way for the realization of requisite variety within the ED:

> "Besides the involvement of departmental personnel in constructions, we've also created a crew which operates both old and new (electrical) units. [...] This ensures the direct inflow of information, which is very important for us, since we have to maintain these units from time to time."

Both the Cultural and Satisfaction Survey and discussions reveal that maintenance personnel are not opposed to the opportunity to familiarize themselves with newly introduced technology, and frequently have the opportunity to work overtime thus adding to their income. Although this seems to be a win-win situation for all involved, many middle managers complain. For example, the response of the RED head is indicative, while concurrently highlighting the sense of crisis:

> "Constructions tie up valuable resources in strict timetables and this makes their withdrawal and reallocation elsewhere in case of an emergency very difficult."

However, the same department head added:

> "I recognise that the involvement of maintenance personnel in new projects is an excellent on-the-spot training opportunity."

Notwithstanding, a SED supervisor indicated restrictions in the provision of equal opportunities:

> "(New) constructions always involve the same people."

Furthermore, and besides personnel involvement in new technologies during unit constructions, technological change (Tushman and Anderson 1986) within the MD cannot be neglected. Hence, the adoption of new equipment is perhaps the most common form of technological change in maintenance working life. A closer inquiry into this aspect revealed a considerable variation in the spectrum of technological changes across maintenance departments. On the one hand, the ID provides a case in point since it appears to both benefit and suffer the consequences from the rapid technological changes. The department head explained:

> "Yes, we are heavily influenced by the developments in new products, since every two years suppliers launch a new product series. [...] Sometimes these are not very different and there's no need to spend money and time on learning how to use them. But instrument technology has demonstrated significant progress and many times it has changed the scenery completely. Suppliers want to push their products and stop offering spare parts for older series of instruments, forcing us to change all existing instruments of similar technology, having become outdated with the launch of the new series."

The head also added:

> "We're in constant pursuit of technological advances. [...] This is an important responsibility of the department to adjust in a new operation mode, since technology changes our working practices. [...] For example, new digital instruments are more sensitive than older series and there aren't many ways to repair them. When technicians realize a malfunction they simply replace them. So, technicians have to learn new methods of testing and calibrating the new instrument and verifying that it's functioning properly."

The department head explained the triggering of a learning process:

> "As the years pass, you acquire the experience to cope with such situations. You learn how to learn. [...] We need a period between six to twelve months in order to say with confidence that we can operate an instrument in a variety of conditions, including operating and environmental conditions that often bring the equipment to its limits."

A senior consultant seemed to understand the issue of technological change within the ID:

> "Instrument technology has changed rapidly within the past ten to twelve years. Pneumatic instrument technology of the early '90s was replaced by electrical instruments with the introduction of PLC technology. Then, within a few years, we had DSC technology, which was replaced again by SCADA systems; while nowadays we're talking about artificial intelligence."

A similar example of frequent technological alterations was provided by a RED engineer who explained that pumps change every four or five years with improved shafts, anticorrosion alloys, or a different internal structure due to developments in fluid dynamic:

> "New product generations made our technicians receptive to change. [...] They're used to minor or major changes to working practices in the maintenance of such equipment."

In contrast to the ID, the SED occupies the opposite extreme in the spectrum of technological change within the MD. The SED head explained:

> "We've been maintaining the same vessels and heat exchangers for approximately twenty years. The same happens with the distillation column, which remains in position for a few decades just like many other equipment categories we maintain. [...] All these years we deal with the same problems on the same equipment. Don't forget that refining processes haven't changed for many decades. [...] Our work is limited to pipe replacements or welding the walls of vessels."

However, the department head recognised that many changes have happened to the instruments that control their equipment. Indicatively, a SED supervisor with twenty-five years' experience said that the only significant technological change that comes to mind concerning departmental works is the change of the inspection equipment that belongs to the Inspections Department. The supervisor said that ten to twelve years ago they needed a truck and at least three people to carry the ultrasonic inspection equipment (for the vessel inspection), but nowadays this equipment is the size of a small calculator.

Besides job rotation and technology as factors that contribute to the enhancement of adaptation to various internal and external changes, such adaptation and flexibility is prevented by factors connected with the maintenance organization structure, which is neither flat nor flexible. For example, the Collective Labour Agreement reveals the existence of an organization with many hierarchical levels linked to seniority and salaries, and to professional rights and academic qualifications. Conversely, the creation of additional levels and departments, such as the division of the Mechanical Department into two departments when there was a substantial increase in the workload, indicates a relative rigidity of the MD to environmental fluctuations.

Additionally, the hierarchical and inflexible structure of the MD is coupled with an information network incapable of providing individuals with fast and equal access to vital information and eliminating existing information differentials. An example of information differential within the MD concerns information inflows to the PD. Hence, interviews revealed that the PD personnel know where information is located, as a RED engineer explained:

> "The PD is usually more accurate in identifying which department is responsible in case of equipment faults than the operators, who usually call two or three maintenance departments."

However, the same engineer highlighted that planners do not have access to vital, up-to-date information concerning internal and external changes that have an impact on maintenance activities, and this inhibits them in responding appropriately to environmental changes:

> "Planners work in isolation in their offices so they aren't expected to be informed about everyday working activities, such as delays in the use of resources, either in the units or the workshops. [...] They usually find out what's happened after the execution of the job. [...] Hence, they can't create an applicable maintenance schedule."

The PD head confirmed this by saying:

> "Supervisors of the other maintenance departments, who're present and acquire such information directly, are responsible for the scheduling of maintenance activities."

The potential role of ICT in creating a virtually flat organization (Brown and Duguid 2000) is nullified since the existing ICT applications, the CMMS and the CWMS operate in isolation in the PD and the WD. As a RED engineer added:

> "The system (CMMS) is used solely by the PD. We (other departments) neither have access to its information, nor do we consider it a potentially useful tool."

In addition, meeting notes taken during discussions about the potential use of information maps, which would explain who would be responsible for the execution of each step of maintenance procedures, provide an insight into the existing information network in the MD. Thus, the supervisors' group indicated the existence of a complex and informal information network. The RED supervisor noted:

> "Such information maps aren't applicable. When we want to find out something we have people in key positions that provide the necessary information."

An engineer from the same department added:

> "Normally, information isn't derived from an expected source. [...] Staff uses unorthodox ways to acquire information."

An ED engineer noted that information flows are vested in power relationships:

> "The allocation of roles for the provision of information in maintenance processes won't work due to existing power relationships controlled by those who execute the work."

5.7 Moving ahead with a blurred vision

The MD had never had an official mission statement or well-defined objectives to guide its activities, to coordinate the creation of technical know-how, or even to shape an integrated culture. Top, middle and lower management verified during discussions what the head of the Investment Programmes has said:

> "The only objectives in here are the production targets of the OD."

In addition, a top manager responsible for the company-wide SAP implementation noted:

> "Petrochem and the MD started introducing policies for the first time in 2001 during the corporate ERP system implementation."

However, Petrochem has had a corporate vision at least since the beginning of 1990s. This is presented in Figure 5.1, and describes the aim for corporate transformation into a fully integrated energy group.

Figure 5.1	**Petrochem's Corporate Vision**

Petrochem's corporate vision is the engagement in commercial, industrial and production activities with regard to hydrocarbons in Greece and abroad, including:

- Hydrocarbon exploration and production.
- Refining of crude oil, production of petroleum, chemical and petrochemical products.
- Supply, transportation and storage of crude oil and its derivative products.
- Trading and marketing of petroleum, chemical and petrochemical products.
- Marketing, production and operations in every other form of energy.
- Provision of advisory services on issues and the study, supervision, construction and management of projects relating to hydrocarbon matters.
- Contracts with the Greek State in pursuit of the exercise and management of its rights and interests in matters connected with the objectives of the Company.

(Petrochem's Company Presentation - 4th Annual Capital Link Forum Conference, NY, 30 October 2000)

Moreover, Petrochem has also consistently declared in every annual report since 1998, its policy on social responsibility (See also Appendix Four). Within the framework of this policy the company completed a series of environmental programmes in order to improve the quality of life of the near-by municipalities' citizens. During an informal discussion a top manager said:

> "Many of the refinery's low-level employees live in the nearby municipalities, which are directly affected by our production activities. These employees feel more confident when they know that the company in which they work takes precautions for their living environment. Besides, you realize that since the wider area is industrialized, everybody is very sensitive to environmental protection, and especially the authorities of these municipalities."

In addition, Petrochem organizes guided educational tours to pupils, students and scientists from schools, universities and institutes from all over the country.

Notwithstanding, the Cultural and Satisfaction Survey revealed communication problems at all levels, since maintenance employees are not familiar either with this corporate vision, or even with any MD objectives, either official or unofficial. In addition, according to the survey, goal clarity is also limited, and methodologies for the achievement of goals are equivocal.

However, the non-existence of a steadily communicated vision is also connected to the existing reality. A SED engineer pointed out something that was also evident in the Cultural and Satisfaction Survey. This relates to the fact that the MD operates with a relatively short time horizon and in a reactive mode:

> "With the current situation we're unsure about tomorrow morning's activities, so what sort of long term planning and vision are you talking about?"

In addition, the same survey indicated that the MD is not worried about local competition, since the Group feels superior and invulnerable. An OD engineer explained:

> "The size of the local fuel market is very small and the size of Petrochem ensures our advantage."

During discussions, the assistant maintenance manager also noted:

> "The refinery maintenance personnel are highly skilled. We have the most competent maintenance team in Greece and this is a reason why the survey indicated that personnel aren't worried about competition."

The SAP top manager said:

> "The competitive advantage of this Group is the (Greek) government and the protective environment within which it operates."

Discussions also related security in relation to the financial operating environment, which has made the Group patient and rather reflective to environmental changes. A RED engineer said:

> "Financial worries entered our life only after the entry of the Group on the stock market."

However, and despite the communication problems and the corporate vision, which is not oriented towards external competition, the inquiry did uncover knowledge creating directives within the company that consist the elements of a blurred knowledge vision, since they are ambiguous enabling multiple and often contradictory interpretations. These directives reflect top management's desire, as expressed in discussions, to create a safe working environment that will secure the best possible equipment availability for production, and the view that "maintenance should not interfere with anybody's work (meaning the work of the OD)". Besides, the Cultural and Satisfaction Survey indicated that maintenance employees believe that they have an external orientation consisting mainly of a focus on OD's needs, and they are also proud of the quality of the services provided.

Hence, many engineers and department heads explained in interviews that these directives, which reflect an engineering culture (Schein 1996), aim at ensuring the operation of production equipment, either by improving reliability or by ensuring prompt emergency repair, and at protecting the environment and improving work safety. The assistant maintenance manager provided an example, indicating how the MD created technical knowledge about the operation in a safer mode with the introduction of equipment condition monitoring and the technique of shaft alignment, resolving compressors' reliability problems that caused frequent incidents:

> "The refinery has had in place preventive maintenance programmes since the beginning of the 1980s. For example, since then the refinery applies laser shaft alignment. That period was rather difficult for the refinery, which has been in operation since the mid 1950s. The previous major investment had taken place in 1970, and at the beginning of the 1980s we had equipment reliability problems. [...] We had serious problems with compressors. One of the major problems turned out to be their shaft alignment and their operational condition monitoring. So, we decided to introduce a new technique to cope with shaft alignment. We started aligning shafts with the use of laser technology. This technology was very expensive at that time. At my initiative we added instruments to the compressors in order to monitor their operation. Within three months we reduced accidents with compressors. Before the introduction of this technique we had incidents with compressors each week. And they were very serious incidents, which often caused injuries to workers. There is no need to mention the impact of these incidents on production or on the environment. [...] In 1983 we were one of the first oil refineries (worldwide) to use laser shaft alignment. I was the refinery representative at an International Conference for Oil Refining and someone made a presentation about the value of this technique for improving compressors' reliability. The man asked the audience if there were any refineries that use the technique. There were representatives from more than 100 refineries there. Only three refineries were using that technique and our refinery was one of them. The other two refineries were located in the USA. Our refinery engineers were very proud of this."

The assistant manager also explained that the realization of the MD vision for safe operation was recognised at a formal ceremony that fostered trust among employees:

> "The Employee Union organised a ceremony in which I was given an award for my initiative to introduce instruments for monitoring the condition of compressors. [...] This idea reduced the number of unexpected fires in the compressors and made the employees feel that they work in a safe environment. I was one of the newest engineers at the refinery then."

Furthermore, another example of an objective pursued by the MD was provided by the SED head, who explained that the MD personnel are trained in maintenance skills. This is rare in Greek industry and is usually acquired from foreign contractors and equipment suppliers:

> "Most of our equipment suppliers are located abroad, in the United States, the UK, the Netherlands, Scandinavia, Japan or even Korea. When you request them to come, even for a simple inspection, they will charge you as much as for a new piece of equipment! In addition they aren't available when you want them! Sometimes you have to schedule their travel many months in advance. The local equipment supplier representatives complicate the situation and they rarely provide the necessary skills and know-how for maintenance. Therefore, we train our personnel on how to maintain this sophisticated equipment. [...] In many cases we've sent our people to other Greek industries to maintain similar equipment."

Moreover, the existing directives influence departmental policies, such as the case of the WD, which arranges its spare part stockholding policy with the basic criterion of avoiding complications related to the geographical location of the refinery. A WD engineer said:

> "Many spare parts coming from the Greek market arrive within a day or a week. However, most of our suppliers are located abroad and the spare parts need many months due to the fact that they're customized for our refinery. And let me give you another example. Can you realize the delays we had in spare parts during the bombing of Yugoslavia or with the civil disorder in FYROM? Most of our spare parts arrive here either by railway or by truck, which come through Yugoslavia. Since then, many of our suppliers send spare parts through Italy, but it's an 18-hour trip just to cross the sea. Maybe this is a rather extreme example but it's a real one. Anyway, in general, spare parts that come from abroad take longer to arrive, meaning that we have to adjust our stockholding policy appropriately."

In the absence of a formal communication channel for the above-mentioned knowledge creating directives, middle managers not only interpret them into the study and use of sophisticated techniques or equipment developments, which enable the refinery to operate in a proactive mode, or to minimize the impact of reactive maintenance, but also set the example for other employees. The assistant maintenance manager explained that "traditionally, the MD dealt with the absence of written objectives or mission statements with management-by-example set by engineers" that transmits and communicates embedded objectives to personnel. Moreover, the communication of the knowledge creating directives of top and middle management in the informal and rather personal way of example setting is assisted by the fact that Petrochem has always developed its own managers from within the organization.

The construction of the refinery substation network with autonomous electricity production units, described in detail in Appendix Three, is an indicative example of how middle management interpreted and articulated, both horizontally and vertically within the organization, a vision provided by top management that formed a new reality. The ED head explained that top management demonstrated trust as to the competencies of engineers:

> "After the (1988 nationwide) blackout (of the Public Electricity Company) refinery top management decided that the dependency on the national grid was an underestimated risk. The executive board decided that the refinery should be able to operate autonomously. [...] Well, obviously blackouts were a threat to the brand new units that were added in the 1987 revamp, but some political pressures also led to this decision. Since, then, this refinery was the only state refinery and the only fuel supplier of the Greek army. [...] MD electrical engineers suggested the creation of a substation network with autonomous electricity production units. [...] We also undertook the responsibility for their construction. [...] Now the refinery has perhaps the only team in Greece with the skills and the know-how in designing and constructing industrial substation networks for such purposes."

Furthermore, an engineer from the same department noted that the refinery also developed difficult-to-imitate skills:

> "Not only did we acquire skills in the construction of substation networks, but we've also developed and patented a customized methodology for their operation."

5.8 Summary

This chapter has attempted to describe aspects of the conditions and knowledge vision at the MD that stimulate individual and group interactions. The research uncovered contradictory evidence concerning the conditions of trust, care and commitment, which vary across hierarchical levels, maintenance departments and refinery divisions, while demonstrations of lack of trust and low care relationships are frequent. Among other things, lower management influences the process of trust building and regulates personnel commitment. The investigation also provided insights about autonomy and argued that despite the restrictions imposed by the organizational structure, autonomous teams do exist and operate under the control of the supervisors. Autonomous action by employees at the middle management or higher levels is unobstructed, while autonomy to experiment is encouraged and supported due to its potential benefits. Moreover, the navy culture of the OD is a primary reason for evoking a sense of crisis in employee interactions and has been present within Petrochem for many decades, promoting mistrust between the MD and the OD. Furthermore, the investigation indicated that redundancy of information within the MD has been achieved traditionally and primarily through job rotation. Additionally, the inquiry showed the dual face of requisite variety within the MD, of opportunities for personnel to combine information and knowledge differently, and of examples that demonstrate impediments to equal access to information. Finally, this chapter described the existence of embedded and rather equivocal objectives in the everyday activities of the maintenance organization that substitute for the lack of a solid knowledge vision. We turn now to a description of the maintenance service work in Petrochem.

6

The bittersweet Fruit of Knowledge Creation at the Maintenance Division

6.1 Introduction

Having described in chapters four and five both the case organization and the general conditions for knowledge creation, this chapter narrates the story of maintenance service work at the MD through a knowledge creation perspective, utilizing the Unified Model of Dynamic Knowledge Creation.

We first deal with the acquisition of maintenance skills, with the transfer of information and with information collection from within and outside the MD. This first section is also concerned with the deliberate or spontaneous interactions that facilitate these processes. For this reason a description is provided of the skill acquisition process for various hierarchical levels, as are a number of examples that characterize not only this process, but also knowledge acquisition and transfer. In doing so, an attempt is made to demonstrate some of the face-to-face socialization interactions. Furthermore, these interactions are linked with concepts of care (Von Krogh 1998) and trust (Newell et al. 2002) relationships, and with improvisation (Ciborra 1997; 1999a; 1999b; Weick 1998; Moorman and Miner 1998).

The second section explains how maintenance personnel use acquired skills and know-how in order to formulate hypotheses about equipment faults and to build maintenance repair concepts. By describing who and how participates in this process through the established procedure for requesting and authorizing maintenance work, this section presents the creation of two different kinds of repair concepts: preventive and reactive.

The third section describes the planning and scheduling process of maintenance works through the story of the maintenance Job Plan used in the refinery. The section uncovers the complex contribution of explicit knowledge sources and a number of other associated issues, such as the existence of reports and databases, and the utilization of ICT.

The chapter also deals with the execution of maintenance repair based on the Job Plan. Thus, the final section describes the multi-actor job execution routine that has two fundamentally different aspects: preventive maintenance and reactive maintenance. This organizational routine is frequently coupled with experimentation and simulation.

6.2 Socialization, skill acquisition and information collection

MD personnel have not only lived in the same environment at Petrochem for a significant period of time, they also spend much time together. The Maintenance Personnel Database reveals that two thirds of the maintenance employees have been working at the refinery for a period of approximately fifteen years, eighty percent of all personnel have been employed for more than ten years, whilst employments during the past five years have been extremely limited. A SED supervisor noted:

> "The crew members spend all of their time together".

Of all hierarchical levels of the MD, the supervisors' level is considered the most experienced, since their average employment period exceeds twenty-two years. Discussions with top and middle management during training seminars demonstrated the existence of trust and wide recognition of their skills. The ID head stated:

> "Yes, supervisors are experts in their areas and challenging them is extremely difficult."

The existing labour legislative framework favours long-standing personnel in the MD by enforcing privileged job security and making the redundancy of personnel extremely difficult. Individuals are given the opportunity to share experiences and familiarize with the diverse worldviews of fellow colleagues. During an informal discussion an OD engineer mentioned:

> "When you know that redundancy is highly unlikely, you express your opinion freely without fear, even in cases where this contrasts with top and middle management."

Hence, this symbiosis of the maintenance personnel, which sometimes can be more or less harmonious, creates an environment for socialization and skill acquisition. Within this environment all low-level maintenance employees participate in the mandatory traditional apprenticeship during job rotation and are exposed to hands-on experiences. Interviews with supervisors indicated that apprentices learn their craft by attending both official and unofficial demonstrations of equipment repairs. These demonstrations are held by senior technicians, who transfer their accumulated experience, skills and know-how, which in turn they have acquired through practice in the refinery workshops. A SED supervisor said:

> "Senior and junior technicians work together in couples or in larger groups. They spend all of their day together, in the workshop or out in the (production) units, depending on the repair. Junior technicians learn all they know from senior technicians. [...] Usually, senior technicians show them how to perform the task and then let them practice."

An ED supervisor added:

> "Obviously we do not allow inexperienced technicians to touch important equipment, they always start with the easy stuff and gradually move to more difficult jobs. [...] Imagine that in a plant with two thousand (installed) motors opportunities to practice on motor maintenance are numerous, so in a relatively short period of time someone who works in the Motors Crew, will have the chance to undertake more responsibilities. [...] The supervisor and the senior technician always keep an eye on technicians and make sure to correct mistakes."

A SED supervisor explained that supervisors trigger this process:

> "Since the responsibilities of the supervisor are enormous, we can't devote much of our time to a particular individual. We choose what skills they (technicians) should acquire, but senior technicians undertake the tedious task of training newcomers. [...] Senior technicians organise small groups and demonstrate maintenance techniques and practices. These "lessons" are mainly on the spot and usually on pieces of equipment that are worth showing. [...] Senior technicians sometimes pay particular attention to specific individuals, either because they are convinced that it's worth investing in them, or because they have to acquire at least the basic skills."

Furthermore, apprenticeship covers the need for the knowledge transfer to newcomers from their senior colleagues, due to the lack of an official training programme. A WD engineer said:

> "There's no official training programme for warehouse personnel. Employees come here and learn things by watching others. [...] The more experienced workers teach them how to use the Warehouse Management System. Then, we send them outside to start learning the different spare part areas."

Similarly, a PD engineer explained that newcomers learn how to use the CMMS and to handle requests for maintenance work.

The basic stage of skill acquisition through apprenticeship is completed when low-level employees acquire licences and other qualifications and they are allowed to participate in everyday working activities. A RED supervisor confirmed during the training seminars:

"Almost ninety five percent of our technicians have gained skills within the refinery which are certified either by the Greek State or by other professional organizations."

An ED supervisor added:

"Technicians without qualifications aren't allowed to go into the field (the production units) very often."

The acquisition of maintenance skills, especially of those that are rare in Greek industry, is facilitated by their diffusion through face-to-face interactions. For example, the SED head explained:

"The training of employees in order to be in position to maintain complex equipment is extremely expensive. So, the first forethought of the Division is to spread the skills to other employees. [...] We usually choose a small group of employees and they are trained by an experienced colleague."

The skill acquisition process for middle managers is somewhat different, since engineers not only have a certain educational level, but also because, in addition to technical skills, they need to acquire maintenance management skills. Hence, a senior engineer usually plays the role of the mentor to newcomers. The PD head noted:

"In the absence of a formal training programme, all training is on the job for technicians, whilst training for engineers is a mix of training on the job and training by other senior engineers."

An ID engineer said:

"Irrespective of your previous experience, when you join the refinery you have to revise almost everything. [...] The process of acquisition of new skills starts the day immediately following your employment, when your colleagues give you a pack of documents informing you about your new duties. Colleagues suggest based on their experience, which documents, handbooks and manuals you have to study. [...] The lack of a (standardised) training programme gives these colleagues the freedom to suggest anything that according to their opinion would be helpful."

An ED engineer also explained:

"When I first joined the refinery my colleagues and the department head showed me what sort of documents I had to study. They also offered the kind of knowledge that you won't find in any manual - local technical knowledge and knowledge on how things are done here."

In another interview, the maintenance manager added:

"I remember the maintenance manager, when I was a junior engineer, telling me that he would teach me whatever he knew concerning the refinery management. He had also advised me to practise these managerial skills, to test them and to find a personal style."

Besides skill acquisition, the symbiotic environment within Petrochem provides opportunities to employees for the collection of social and other kinds of information. An example concerns the collection of valuable information and the exchange of experiences during meetings between middle and lower management from the SED and the RED, and during meetings between employees from the ED and the ID. Interactions between employees from these departments that were unified before the 1987 refinery revamp are facilitated by the fact that they share a common educational background, in mechanical and electrical engineering respectively, and a common history. The ED head said:

> "Very often we help people from the ID to identify faults in electrical and electronic instruments. Their work is closely related to our work, so very often we exchange opinions."

In addition, the warehouse provides an example of interactions of low-level employees that promote both information gathering and skill transfer. Hence, workshop technicians exchange experiences with warehouse employees and actually train them, in a rather unusual apprenticeship reflecting a local peculiarity - the new specialty of "warehouse technician". Interviews with warehouse personnel revealed that the pressing need to identify the required spare parts for maintenance repairs made the workshop technicians help warehouse employees understand craftsmanship and transferred to them expertise derived from accumulated experience and extensive practice in the workshops. Additionally, warehouse employees trained the technicians in the use of the CWMS. Thus, a WD engineer explained:

> "When technicians need one of the fast-moving spare parts it's quite easy to identify it using the existing system. However, in many cases, neither our personnel nor technicians are capable of identifying the exact name of the spare parts and their location. [...] The sure thing is that we have to give them a spare part to do their job. In cases where they can't find the part they're looking for, they start wandering up and down the warehouse corridors in order to track it down. [...] This usually takes a few hours and in many cases a few days."

The same engineer explained that problems in spare part identification are due to physical and organizational restrictions (see also Appendix Three) since the warehouse contains approximately two hundred thousand spare parts placed on five-meter tall shelves in an area of many thousand square meters, whilst often existing warehouse management procedures, such as registration of spare parts, are not effective, and personnel are not adequately trained. Consequently, these operational problems prevent the WD from providing spare parts for repairs quickly especially in emergency incidents.

This need creates spontaneous interactions when the warehouse worker and the workshop technician join forces and look for the particular spare part in pairs. The WD engineer explained how workshop technicians transfer knowledge from the workshop to the warehouse during these interactions:

"Well, the technician and the worker spend much time together. Imagine a pair of two people. One of them, the warehouse worker, has some information about the spare part, such as the frequency of use, and the other one knows the physical appearance of the spare part, knows how and where it will be used. It's a natural consequence that the warehouse worker learns a lot from this situation. [...] For example, some spare parts must be stored and handled in a certain way. Sometimes the suppliers give us such instructions, but the technicians do most of the work (provide information about the handling of spare parts)."

Moreover, these interactions foster warehouse personnel's sympathy for and leniency towards technicians. The WD engineer added:

"Despite the fact that sometimes technicians don't register the spare parts they take, and they also have an aversion to completing forms, in general they help us overcome the difficulties that stem from the poor spare part classification."

The same WD engineer explained that the skill transfer process during these warehouse interactions is two-way:

"We (WD) train the technicians as well! Do you know that there are technicians fully trained in the use of the CWMS? [...] Yes, they've spent so much time in the warehouse looking for spare parts together with our personnel that they started using the system. [...] Some of them have become extremely competent. I could say that they have become an extension of our personnel and they have acquired a new speciality. They've become warehouse-technicians."

The phenomenon of technicians identifying spare parts along with WD personnel is so frequent that each maintenance department has unofficially established one or two resident representatives, who dedicate their time to this activity. This is done with the support of middle management, who realize the benefits of such socialization interactions. The WD head said:

"Yes, technicians train the warehouse personnel. After all, they use these spare parts and they have to inform us, and why not train us, if they want us to treat these parts appropriately."

Moreover, these warehouse interactions are linked to the concept of tinkering (Ciborra 1997; 1999a; 1999b), since warehouse-technicians often decide to construct spare parts they cannot find in the warehouse and the purchase of which may require some time. A WD engineer explained:

> "The construction of spare parts that are not found in the warehouse is not something rare. [...] During the searching at the corridors of the warehouse technicians with the help of our personnel find substitutes, which are used for the construction of the same or similar spare parts."

The SED head added:

> "Spare part construction is also a very common case of modification. Sometimes the unit location is differentiated from the original design and we have to modify some parts. In other cases technicians have found that some small modifications would avoid blockages in pressure relief valves and then we modified almost all of the existing pressure relief valves. And one of the most important factors that pushes technicians to modify spare parts is spare part availability. When we don't have the required spare part we construct one."

In addition to the WD example, the PD head indicated another frequent opportunity for the collection of intra-firm information:

> "New constructions offer opportunities for socialization. We spend much time with colleagues from departments, such as the Process Division and other administrative departments, we don't see very often."

Moreover, the MD gathers knowledge from face-to-face interactions with colleagues from the second refinery of Petrochem during personnel exchange trips. The ED head explained:

> "(Personnel) visits to the second refinery of Petrochem are frequent and they aim at the exchange of know-how and experience. [...] Despite the fact that the second refinery of Petrochem is not as technologically advanced as this one, it's been operating with the use of Exxon standards and practices for many years before its acquisition by the Group; hence, colleagues have acquired an organized culture and their opinions are very important. [...] For example, recently the second refinery decided to establish an Advanced Process Control System and they visited us in order to discuss our experiences with it, since we've operated a similar system since 1996."

Opportunities for the promotion of socialization interactions are also provided, amongst other things, by the employee union, which organizes informal social meetings both inside and outside the workplace. An examination of the research diary reveals that within a two-year period, the union supported the organization of two fire prevention demonstrations and encouraged employees' participation. The Union also organized a series of social events, such as two book exhibitions offering fifty percent discount, five blood donations for the local general hospital, two annual dance balls, a fund raising for the donation of an El Greco painting to the Greek National Gallery, and a painting contest for the employees' children. The Union also distributes discount theatre tickets to employees twice a year and offers a free summer camp for employees' children. It also issues and distributes a weekly newsletter with news and criticisms on corporate and other contemporary developments with an impact on the working life of employees. Its activities often have strong political undercurrent, such as the organization of a series of strikes against the forthcoming privatisation of Petrochem and demonstrations against the further development of a nearby factory, which would undermine the life quality of the local municipality. A top manager said:

> "The union often influences our decisions, since they have considerable influence, especially on low level employees."

Many of these Union activities were supported financially and energized by top management - except the strikes. The technical director of the refinery explained top management's intentions:

> "We (top management) don't support all these activities (theatre tickets, book exhibitions etc.) because of an obligation that stems from an agreement, but in an effort to create a human atmosphere and to ensure employee motivation. [...] I can assure you that this kind of policy pays off especially in emergencies in which the support of employees is important, and it reduces many of the existing organizational problems."

Furthermore, the interactions of the MD with external suppliers, equipment manufacturers and contractors are also an example of external knowledge acquisition and exploitation. Middle management select technologies and applicable methodologies, whilst supervisors connect the refinery with external groups based on perceived trust of the contractors' and suppliers' competencies and on the technical quality of executed works. A RED engineer noted:

> "Equipment suppliers and contractors have input into the discussions about the causes of damage and necessary repairs, and they also provide information about new products, services, maintenance strategies and the market situation. The contractors are private companies and they have the flexibility to propose new maintenance techniques. Of course they're trying to sell something, but we have the opportunity to get information about state-of-the-art developments."

Additionally, supervisors act complementary to engineers. A RED supervisor explained:

> "A contractor who failed in the past to provide quality work is unlikely to return to the refinery. [...] We advise engineers about their (supplier's and contractor's) skills."

The interview with the same RED engineer also indicated that relationships with contractors are beneficial for the MD:

> "Well, you've just mentioned the problem with the small Greek market[52]. So if you train a contractor to maintain your equipment in the way you want there is no reason to destroy the relationship. Then we ask them to do more things, which they do. And bear in mind that if they wanted to refuse, they would just stick to the contract, but they don't."

[52] Note: There are only a few maintenance contractors and competition is limited

Skill acquisition and knowledge collection during the everyday working life at the MD are promoted through face-to-face interactions, in both deliberate and spontaneous gatherings. Interviews and observations revealed a number of places available for the hosting of such interactions. Top and middle management interactions are hosted in the offices and the meeting rooms of the administration buildings. Perhaps the most indicative example of interactions amongst these two hierarchical levels takes place every morning in the meeting room of the old administration building at 7:30 am. There, the maintenance manager invites the department heads and their engineers, and informs them of current developments related to decisions of the corporate executive board. An ED engineer noted:

> "It's an unofficial meeting. The politicians call it "morning coffee meeting". We gather and discuss the progress of the maintenance workload for twenty to thirty minutes. We exchange opinions about the emergency incidents of the day or of the week. [...] Of course, we discuss a variety of other things such as the current political developments in Greece, sport, etc. It's an unofficial meeting and when we don't have many things to discuss concerning the maintenance activities we chat about a variety of other topics."

Besides discussions about the workload and the fortification of personal relationships, the morning meeting is also responsible for many improvisations. The PD head explained that minor or more major improvisations (Weick 1998; Moorman and Miner 1998) concerning the execution of maintenance activities are also decided:

> "During the morning meeting we have frequent overturns of the daily and weekly maintenance plan. [...] We decide reprioritizations or cancellations of the maintenance works depending on the prevailing circumstances. [...] Yes, it's the only time in the day in which we have the opportunity to discuss the progress of (departmental) works, and we draw the big picture."

Additionally, and besides the morning meeting, the offices, the meeting rooms and the workshops host socialization interactions within Petrochem. A PD engineer noted:

> "Corridor and office discussions provide a first-class opportunity to learn from colleagues not only about technical aspects of the work, but also about important news about the company."

Moreover, an ID engineer explained middle management interactions in their offices:

> "We spend most of our working day in the office, either discussing with colleagues and suppliers, or doing administrative work, studying and preparing for new projects."

Face-to-face interactions are also promoted by the existence of an open-door system in the maintenance building, which is located next to the workshops, thereby allowing communication between engineers with supervisors and technicians. An ED engineer explained the advantage of this system and highlighted the occurrence of frequent meetings both - spontaneous and deliberate - with lower management and the crews:

> "Yes we have an open door system so that the engineers can contact and communicate immediately with the technicians and the supervisors in the workshops. [...] Well, yes, we have meetings very often, either at the offices of the engineers or at the workshop. First of all, we have the morning meeting of the department heads with the maintenance manager. Then, each department head or the engineers have morning meetings at the workshop with the supervisors and some of the technicians. [...] Of course the engineers go at regular times to the shop-floors to check on the progress. [...] The morning meeting at the workshops is the equivalent of the engineers' morning meeting. [...] It's very important for each department, since it's maybe the only meeting in which almost all of the departmental engineers and supervisors participate before their work absorbs them. [...] The topics of discussion are mainly work-related, but often other issues are discussed as well."

However, and while middle management move freely between meetings with top and lower management, supervisors move between the units and the workshops, coordinating crews and technicians. A RED supervisor said:

> "Every morning we visit all our crews at the units and workshops. [...] For example, we inform workshop technicians about the repair situation in the units."

Additionally, besides the offices and the workshops, a number of other places promote face-to-face socialization interactions, such as the canteen and the near-by rest room. Thus, everyday during the 10 o'clock break, refinery technicians socialize with technicians from external contactors. A RED engineer pointed out that these interactions foster care relationships (Von Krogh 1998):

> "Well, yes, I believe that relationships between refinery technicians and external contractors' technicians are very good. Many contractors have been working at the refinery for more than ten years and they've become very good friends with refinery employees. In fact, an external contractor became the best man at the wedding of a technician from our department!"

Moreover, observations in the canteen revealed that technicians discuss a variety of topics, ranging from football to technical solutions to problems. The same RED engineer also noted that very often contractors transfer experiences to technicians:

> "Despite the fact that we're one of the most technologically advanced industries in Greece, which means that we're often the ones who train contractors, external contractors' technicians work in other industries and often bring in useful know-how."

The refinery restaurant is another place, which contractors are not allowed to use, for socialization and information collection. The participation of the researcher in many discussions with the maintenance personnel indicated the importance of this place for face-to-face interactions. Many times personnel spent more than an hour in the restaurant discussing a variety of topics. A PD engineer said:

> "During lunch we have the time to relax, lay back, enjoy ourselves or even think about the follow up activities of the day. [...] You know, we discuss everything from politics and sport to issues concerning our work."

Additionally, opportunities for socialization interactions are provided every morning and afternoon in the locker rooms and in the busses that carry employees to their homes.

While MD employees are given the choice of using virtual media as a means of facilitating their face-to-face interactions in the above-mentioned examples, they tend to neglect them. A RED engineer noted:

> "Engineers collect lots of useful information from external suppliers over the phone, but very often suppliers are asked to visit the refinery to discuss things face-to-face."

Furthermore, at Petrochem, the use of virtual media, such as video conferencing technologies, is not as wide-spread as it could be. Both management and employees believe in the value of face-to-face interactions and this becomes evident when considering the amount of expenses paid for travel between the two largest refineries of the group, despite the availability of video conferencing facilities. A top manager noted:

> "As far as I'm concerned, this system cost millions (drachmas) and it has been used only a few times for discussions with international partners. I guess that refinery personnel prefer on-site visits and face-to-face discussions."

Nevertheless, socialization, skill acquisition and knowledge transfer interactions at the MD are frequently influenced by functional and hierarchical boundaries, and by the existence of trust and feelings of care. In fact competence trust (Newell et al. 2002) is a prerequisite for both professional and social interactions. An ID supervisor said:

> "The core of each department consists of a team with blind trust in the abilities of their colleagues. [...] All people in departmental key positions belong to this team: the department head, the senior engineers, the supervisors, the senior technicians and many of the technicians. [...] Yes, one reason is that we've been working together for more than thirteen to fourteen years. It's natural that after so many years you can't treat your colleagues with indifference. And surprises are rare. I know what to expect from them (colleagues) and they know what to expect from me. [...] I expect excellent performance when this is required in our job."

In addition, the SED head explained that departments avoid interactions with employees who are not trusted:

> "If you don't trust your colleagues then you're probably in the wrong department. According to my experience, people who didn't fit in their departments were transferred somewhere else. The "fridge"[53], is always an option for those who aren't trustworthy."

Additionally, horizontal interactions amongst supervisors from various maintenance department facilitates the collection of intra-divisional information that result in modifications in the maintenance schedule by rearranging the sequence of activities in a work in progress. A RED supervisor explained:

> "We usually receive information from other supervisors and then we make the necessary changes. [...] We modify the sequence of the working activities all the time. [...] According to my experience identical cases are extremely rare and this has to do with a number of factors, such as the availability of resources and skills or the existence of other more important cases. [...] You can never know in advance. We usually find out as the work progresses."

However, knowledge gathering faces some hurdles when it comes to interactions between the MD and the OD. A PD engineer pointed out that such interactions are limited:

> "We don't use (cross-functional) teams, consisting of personnel from the OD and the MD to identify and resolve issues that affect both divisions. [...] The only sort of information received from them (OD) is about the identification of the equipment fault."

The same engineer gave an explanation for this:

> "The vast majority of the maintenance personnel sense a feeling of limited appreciation for their job by the OD and this limits any other kind of relationships."

6.3 To be or not to be – the process of fault identification

Accumulated maintenance management and technical skills and knowledge are utilized by maintenance personnel in maintenance activities, which start with a request for the execution of a maintenance task and the associated fault identification process.

Normally at Petrochem, all requests for maintenance work should be streamlined through the official Maintenance Work Order System (MWOS), the operation of which is a responsibility of the PD, with Work Request Forms that describe problems that have to be resolved. The existing

[53] "The refrigerator" metaphor is used extensively within Greek public organizations to describe that an employee with undesired behaviour is transferred to a small department where he will not have the opportunity to interact with others.

MWOS, which defines the procedure through which maintenance work can be requested and authorised for execution, was introduced in 1992 during a restructuring programme of the MD. This led the aim of becoming, according to an old manual, the formal method of requesting, authorizing and recording maintenance work, namely the tool to control and manage all maintenance work. A SED supervisor said:

> "The existing MWOS replaced a very old maintenance work control system that was using a board with magnets representing works. [...] Those were great times! I remember that the old system had made planning and scheduling almost impossible, because magnets were constantly falling off this board and it was very difficult to remember their exact position."

According to the existing procedure for the execution of maintenance work, the requestor has to complete a Work Request (WR) form describing the desired work, explaining both the reason for requesting it and its perceived priority. At Petrochem, WRs originate from many sources, such as from the OD[54], which operates all refinery production units, from maintenance personnel, from the Inspections Department, and automatically from existing preventive maintenance routines. However, the existing automated preventive maintenance programme issues WRs only for a few equipment categories. The PD head noted:

> "There are various preventive maintenance procedures in all maintenance departments, but they are not connected to the MWOS. Only a small percentage of preventive maintenance procedures issue WRs automatically."

Afterwards, the completed WR form is forwarded to the PD, which assigns a unique reference number to it. However, in practice, things are not always done this way. The PD head explained that work requests are not always in written form:

> "A number of maintenance works, especially small maintenance works, are not covered by WRs. [...] The (oral) work request goes straight to the supervisor and they complete the job without notifying us."

In an informal discussion a SED supervisor added:

> "The OD think that minor requests will be lost in the corridors of the PD and they prefer calling us".

In general, the PD estimates that oral requests for maintenance work do not exceed fifteen percent of the total work requests.

[54] The OD generates WRs also during equipment or unit upgrades, modifications or retrofits to the existing production units, which are usually accompanied by a brief feasibility study.

Besides oral requests, and as the PD archives reveal, written WRs contain explicit information about either an already known incident or the possible occurrence of a failure. Indicatively, an OD engineer noted that written requests concern either preventive or reactive maintenance:

> "Work requests can contain any kind of problem description. Sometimes they contain the exact failure reason, some other times they report something, which according to the operator could potentially be dangerous, or some other times they just ask for a simple inspection."

Thus, requests for maintenance work initiate discussions for the identification of actual and potential equipment failures amongst maintenance personnel, unit operators, external contractors and equipment suppliers that bring together maintenance knowledge from various perspectives. The fault identification process involves collective and face-to-face interactions that occur mainly in formal gatherings. A SED supervisor explained:

> "Almost everybody participates in the discussions about fault identification: the engineers, the supervisors, the senior technicians, the technicians. Even the PD sometimes contributes by recalling similar incidents that have occurred in the past."

The existence of a common language within Petrochem becomes the basis for communication between all involved participants. For example, a RED engineer mentioned:

> "People use many naval terms during repairs. [...] Naval terminology was introduced by technicians (graduates of naval schools) but we all use it."

However, and in addition to this rather technical terminology, another example indicative of the existence of a common language is the brush story (described in Chapter Four). Thus, when maintenance personnel want to emphasize the urgency of a maintenance task, they simply say to each other: "Get a brush!", and this is easily understood by everybody.

Once a request for maintenance work is received, a team is formed mainly with the responsibility of a maintenance supervisor in order to examine the equipment. An ED engineer explained the role of lower management:

> "The fault identification teams are usually created by departmental supervisors. [...] Members are selected according to their knowledge and capabilities. [...] Yes, it's natural that trust is an important criterion for selection. Who wants to have untrustworthy colleagues on his team?"

A RED engineer pointed out the changing composition of teams:

> "The team participants, which inspect the damage, aren't always the same. The smallest team consists of the operator and the supervisor. In some cases the team could involve some department heads, engineers and supervisors from different maintenance departments."

In addition, the RED head added:

"The first person that receives information about the incident from the operator and sees the damage is the supervisor. [...] The equipment operator accompanies the supervisor. [...] When the supervisor sees the damage he comes back and reports it to the engineer. If the supervisor is confident that correcting the damage is our responsibility he discusses the repair with the engineer. Very often the engineer and the supervisor inspect the damage again. If the supervisor realizes that the damage isn't our responsibility, he calls the relevant department, gets a second supervisor, an engineer and a (senior) technician, and they visit the unit again."

A RED engineer explained that supervisors are unofficially empowered to take important decisions:

"The engineer goes to see the damage when the request for work is urgent. Supervisors handle the vast majority of the workload successfully without even bothering us."

For the performance of their role, supervisors are the only people from the MD that use a common means of communication in oil refineries, the wireless telephones, since they are the only explosion-proof communication means allowed. The ED engineer explained:

"Only the supervisors and the control room engineers have wireless telephones. [...] Other engineers don't have wireless telephones because they do not need them. The supervisors move all the time, from unit to unit. They need the wireless telephones to communicate with other supervisors. [...] In emergency incidents the operators inform simultaneously the engineer and the supervisor."

The same engineer pointed out that PD supervisors do not use this means of communication:

"PD supervisors don't have wireless telephones. Wireless telephones are expensive and only those who need them have one. The rest of the MD uses normal telephones."

Hence, and despite the control of supervisors regarding the communication of equipment faults, the RED head pointed out that there are cases that attract more participants in discussions:

"The good thing is that rare or unusual cases become known in a very short time, either because technicians boast about their achievements or because we've bumped into a case really worth retelling. [...] I can tell you that there were cases in which we received unexpected suggestions from the most irrelevant (to the case) people, when they found out about the incident. [...] These incidents provide an opportunity for technicians to learn something new."

Nevertheless, the role of middle management is equally important to the supervisors' role. A RED engineer highlighted that middle managers are concerned with financial, safety or legislative issues, and the approval of the final technical solution:

"The engineer is responsible not only for the equipment but also for the safety of the people. The engineer discusses the potential fault with the supervisor and approves the solution. [...] Bear in mind that we don't (always) agree with everything that supervisors propose. Sometimes, their solutions are either expensive or jeopardize safety."

Additionally, a SED engineer pointed out that middle management undertake responsibility for communicating with other refinery divisions and external contractors, indicating the formalised bureaucratic nature of the organization:

"Department heads and engineers approve the technical solution and contact external contractors or other divisions. [...] Well, there's communication between the maintenance supervisors, but there's some sort of a protocol imposed on the communication of engineers when important incidents require the collaboration of more than one department."

Moreover, each employee group contributes to the discussions by providing different perspectives, knowledge and information. The RED head explained this using the example of pump repairs:

"Operators provide information on the symptoms of the pump before the failure. Engineers provide information about managerial aspects of the repair (budgeting); supervisors inform participants about the coordination of planning and scheduling, and technicians provide technical knowledge about the repair."

Furthermore, an engineer and a supervisor from the SED pointed out in interviews that often technicians provide descriptions rich in technical and other important detail that draw a vivid repair model using analogies from similar or other relevant incidents. The supervisor's repair model complements the technician's, since it provides the wider context for the application of the repair. The SED engineer noted:

"The technicians can provide extremely detailed information about the design and structure of the equipment. The supervisors can do it as well, but the technicians give much more detail. They are so experienced that even in cases where they've never touched a particular piece of equipment before, they explain how they think it could be fixed, based on other previous equipment repairs."

The SED head gave another example:

"Corroded and blocked pressure relief valves constitute an important hazard for every refinery. And, indeed, in the past we had frequent problems with blocked pressure relief valves, but we managed to resolve them. [...] A senior technician had seen an anti-block system in a vessel. Then we decided to fit it in a pressure relief valve. We were satisfied by the results and we decided to change all the existing relief valves."

The department head also pointed out that a departmental supervisor was among the first to realize the size of the problem:

> "The problem was known, but a supervisor, after a casual inspection, realized that many of the valves had problems and requiring a solution".

Then, the supervisor's team reflected on this real-world problem and a senior technician intuitively came up with the solution of creating pressure relief valves with an anti-block system.

The SED head also highlighted the role of the autonomous departmental team:

> "The supervisor showed me the senior technician's casual technical drawing of a pressure relief valve with the anti-block system. I was also told that they had started doing some tests. The technician had tested it in the workshop. They also did trial tests during the start up of a unit. [...] Then, I gave them permission to change them all."

However, the head explained that bounded knowledge dissemination took place, since this knowledge remained within the team that dealt with the problem:

> "There were no fireworks for this success, we're the only people who know that, since then we've been working in a safer place."

Additionally, the ID head explained how supervisors ask their crews to contribute to solutions:

> "Supervisors have the most frequent contact with both the OD and with technicians. Usually the (machine) operators report instruments problem to them. When the supervisor makes sure that the problem is not due to the operation of the unit, he starts a thorough investigation with the crew. This investigation requires lots of experimentation both with the establishment and with the operation of the instrument. [...] In the past we found through such experimentation that some instruments were installed in the wrong place. Other times we found that a particular instrument was inappropriate for the unit."

In addition, the same head talked about the role of middle management:

> "When the supervisors come to us, they have some sort of a solution for the problem ready and they either want to inform us, or to get our approval because the solution requires money."

In this fault identification process some groups are either excluded from or do not play a very active role. A SED engineer explained:

> "Yes, supervisors participate in almost all of the discussions for the identification of a fault. [...] Fault identification and the analysis of the required maintenance works are done by the departments that execute them. Participation from the PD is neither frequent, nor enthusiastic, since they don't consider such works as their responsibility."

Furthermore, interactions with other divisions are often simple information transactions (Von Krogh 1998). A RED engineer explained that discussions with the OD and the Process Division mainly concern time-related issues that can evoke a sense of crisis:

> "The input of the Operations and the Process Divisions is to provide information about the impact of the damage to the unit, and about the production schedule and the time flexibility we have in order to find a solution for the damage."

The RED head noted that time restrictions often cause the improvisational adoption of different solutions at different times:

> "Depending on the production plan the solution is different. If the OD judge that they can operate at a lower capacity without the damage causing further problems, we find a casual solution and we fix the problem some other time. In less favourable cases, the OD have a very difficult production schedule and they stop the unit and then we have to repair the damage as soon as possible."

Moreover, time restrictions influence the number of meetings and site visits. A SED engineer explained that, especially in complex cases and in problems that occur for the first time, many meetings take place almost repeatedly:

> "The difficulty of fault identification depends on the case. In usual incidents we identify the problem instantly. Some other times fault identification may take days or weeks. [...] Yes weeks. Sometimes it's very difficult to find one available crane in the market when you need it in order to remove the equipment and take it to the workshop. Some other times the equipment is so complicated that even a careful examination takes many weeks. [...] Identification of routine incidents is quick. It needs a few hours in order to be sure about the fault. For more complicated incidents it takes from three days to a couple of weeks. In other cases it may take more than three weeks. [...] In these cases there's adequate time to discuss the issue with the supervisors, the technicians, the engineers and the contractors."

Furthermore, during the fault identification process, technicians often identify the repair location. A RED engineer noted:

> "The technician examines whether he can repair the damage at the unit or has to take the equipment to the workshop. [...] When a repair takes place at the workshop more people have the opportunity to learn from the incident."

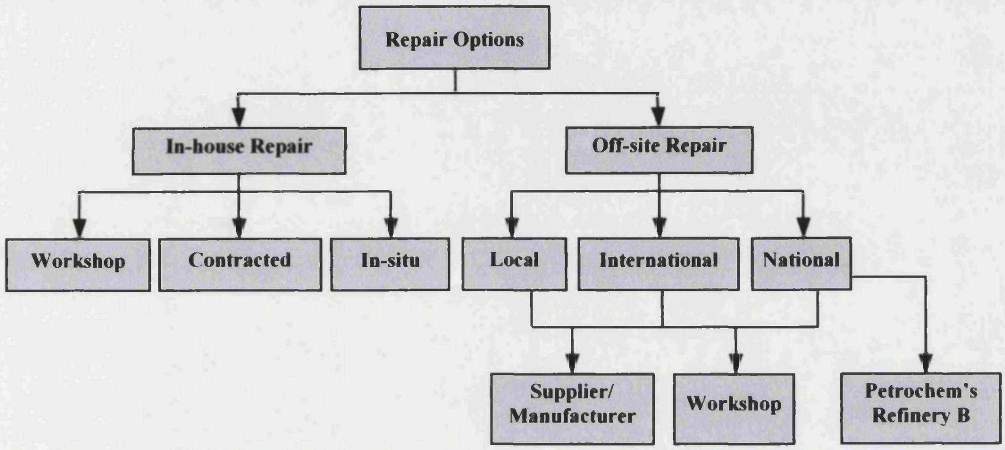
Figure 6.1 shows the possible locations of maintenance repairs.

The fault identification process is a reciprocal process of hypotheses formulation and rejection until the identification of the most probable equipment fault. The RED head explained:

> "Of course, estimates about the problem aren't always plausible or realistic. In those cases we have to re-examine our assumptions and perhaps our expectations. [...] Despite the fact that instinct is

important, fault identification requires close examination of evidence before anyone draws any conclusions, it's not a case of wild-guessing."

Figure 6.1 **Locations of Maintenance Repairs**



Repair	Possible influence of the repair location upon skills acquisition
Workshop	A workshop repair allows the organization of demonstrations to technicians – Transfer of skills and experience
Contracted	The utilization of contractors minimizes the participation of the refinery maintenance personnel – Limited transfer of skills
In-situ	A repair at the unit allows only a small group of people to attend demonstrations on-the-spot - Limited transfer of skills
Supplier/ Manufacturer	A repair at the workshop of a supplier limits the transfer of skills to refinery personnel
External Workshop	Limited transfer of skills to refinery personnel
Workshop at Refinery B	Skill accumulation to colleagues at the second refinery

Maintenance personnel interactions during fault identification facilitate the integration of knowledge and information for the formulation of repair concepts, which sometimes are either well-tested or in other cases include elements of novelty and creativity. Indicatively, the RED head using the example of pump repairs said:

"Yes, our technicians repairs pumps every day. [...] Some incidents are frequent and repairs are more or less standardised, for example, incidents that have to do with inappropriate pump lubrication and the relevant damages. [...] Frequently we deal with cases that occur for the first time even in relatively simple equipment such as pumps. [...] Very often suppliers aren't in a position to help and they answer that they cannot provide assistance since they don't know how we've used the equipment. So, we have to find our own solutions. [...] Fault finding and the repair is a case of trial and error, but sooner or later we find our way through."

Interviews indicated how a hypothesis about an equipment fault develops into an integrated concept about the repair organization and execution in a certain context. An ID engineer said:

> "The mentality of maintenance repairs is simple. Once you find the fault, you proceed with the repair. [...] However, it's difficult to discern between fault identification and repair. We discuss both of them concurrently."

An ED engineer argued along the same lines:

> "We discuss for example that in case of one fault the repair should be like this, or in another fault we should do something else. [...] Experience working here (refinery) has made this kind of response to maintenance seem natural. [...] We manage to organize in-house repairs that other refineries can't perform. [...] Although, it's not easy, we're used to executing very difficult repairs. When you're in a position to do such repairs you approach equipment with confidence. [...] Even in cases when you don't know what exactly to expect, you can understand so many other things that direct you. [...] Well, yes, we receive a work request, let's say, for the electricity production unit. We don't know exactly the problem, but we know that if it remains out of operation in the long term it'll cause problems. Our people (the New Installations Group) who installed it can tell us how much time is required for the opening of the equipment, etc. There's a large pool of knowledge, which allows you to do your job, even if some pieces from the big picture are missing."

Interviews with middle and lower management indicated that discussions formulate in general two fundamentally different kinds of repair concepts: preventive maintenance repair concepts and reactive maintenance repair concepts. Their main difference lies in the fact that the former are much more integrated than the latter. The ED head explained the benefits of preventive maintenance:

> "When you know that something is bound to fail within the next couple of months you have the luxury to examine every aspect of the repair in your own time, without rush, and of course you can take "relaxed" decisions. [...] You can find the right people who'll give you the right advice. You'll discuss with suppliers and contractors. [...] Experience has shown that the quality of preventive repairs is better and we never run out of personnel, spares or tools. [...] Really, personnel enjoy working in such cases."

Figure 6.2 summarizes issues discussed by personnel during preventive and reactive maintenance.

However, discussions and interactions during fault identification and during the creation of the repair concept are rather weakly supported, while in some cases support is non-existent. There is a lack of a structured method for fault identification. A SED engineer pointed out the rather heuristic nature of this process, which is supported by only a few technical documents:

"In fault finding meetings we examine the available information and then we do some brainstorming about the possible ways to repair the damage. [...] Sometimes we go through some technical documents, manuals or maintenance handbooks. We collect information from the equipment operator. Any sort of information provided by the equipment operator may be valuable. We also get production data, about the material (fuel) that caused the problem."

The same engineer also said that the MD had never attempted to use methodologies or techniques, such as Root Cause Analysis or Reliability Centred Maintenance for the structuring of ongoing discussions, despite the fact that a large percentage of middle managers are aware of their existence:

"We've discussed it, but we concluded that most low level personnel and especially supervisors don't have the required educational qualifications and culture to participate."

Figure 6.2	**Questions and Issues that Formulate Repair Concepts**
Discussions concerning preventive maintenance focus on:	
Questions and Issues	**Description**
Repair Quality – Repair Duration	Parameters with economic implications. Personnel identify the desirable level of quality and the time for the repair.
Personnel Availability	Important question during fault identification, if staff is occupied, the time flexibility is critical.
Knowledge Availability	The lack of or the insufficient occupancy of necessary specific knowledge/skills leads, either to training of refinery personnel or to external provision.
Spares Availability	Unavailability results to their purchasing, fabrication, or acquisition through contracted services or off-site repairs.
Auxiliary Tools/Equipment Materials Availability	Unavailability requires purchasing, contracting or examining an off-site repair.
Other Non-Economic Factors	Additional Benefits and Warranty Availability are taken into consideration.
Discussions concerning reactive maintenance focus on:	
Questions	**Description**
Repairable equipment?	If the failure is known, the feasibility of repair is examined or else the item is replaced.
Necessity of immediate repair?	The time limit is influenced by the equipment criticality and the availability of stand-by equipment.
Demanding repair task?	If additional time is available the repair options are examined, in terms of the required repair quality, the usefulness of repair certificates and the repair task safety.

Moreover, and besides maintenance repairs, the MD also uses its skills in other non-maintenance activities as the example of the construction of the first private electricity production unit in Greece indicates. This construction arose, as the ED head pointed out, by top management's desire to "achieve an effective use of local resources and know-how like in the case of the construction of the substations network". At the same time, it was "induced" by middle management, which gathered information during an educational trip abroad about various electricity production technological applications. Hence, middle management came up with the concept of the construction of an electricity production unit with co-generation technology that would operate based on the existing steam production and it would be constructed with the use of local personnel. The ED head mentioned:

> "A departmental engineer was familiar with this (electricity production) technology. He had attended some seminars abroad so he helped in the evaluation and the selection of (electricity) cogeneration technology for the refinery."

Once the fault is identified and the repair concept is formulated, further involvement of the MD personnel either in execution of the repair or even in a new construction requires authorization from middle management. Thus, the authorization of maintenance work signifies the end of the life of the WR document, which is now transformed into a Work Order (WO) since the execution of the work is mandatory. This authorisation signifies also the crystallization of the hypothesis concerning the potential fault and the creation of a concept consisting of written language as to how this fault could be repaired. The WO contains the crystallized repair concept, meaning information concerning the already identified problem, the authorized maintenance work for execution, and in some cases the necessary planning and scheduling details. At Petrochem, the WR and the WO forms are combined for simplicity in a unified document, which personnel call Work Order, shown in Figure 6.3. A PD engineer explained:

> "The advantage of having an integrated document allows technicians and supervisor to identify the requestor easily in order to extract some additional information about the incident."

However, an examination of the WO archives for the period 1996 - 2000 revealed a common secret within the MD, meaning that the reality deviates from the ideal situation concerning the use of WOs. Hence, in most cases, neither the description of the requested maintenance work, nor the relevant field concerning the authorized work were properly completed, indicating that WOs as firm-specific documents are of limited value and it is doubtful whether they are indispensable. For example, the examination indicated that very often the requested work had been poorly described with words, such as "repair" or "inspect pump X", whilst the field for the approved maintenance work contained similar fuzzy descriptions and terminology that made the work unrecognisable even for those who had requested it. Interviews with personnel from the PD and with supervisors from the ID, the RED and the SED revealed that it was extremely difficult to identify both the nature of the requested and the authorized work. A PD engineer noted:

> "It is almost certain that if after a month we show the WR to the requestor, he will not be able to tell us what kind of work he requested, based on the written description. However, this is more or less expected since on average we accept approximately one thousand work requests per month".

In addition, the PD head pointed out the difficulty in utilizing of WOs by people who lack context-specific knowledge:

> "No, the extraction of useful information from a historical analysis of completed WOs is not feasible. First of all, data are not kept with that purpose and then we do not have trained personnel to deal with such an analysis."

Interviews indicated a number of reasons for the miscreation of WOs. First, an engineer pointed at the reciprocal process of the formulation and crystallization of maintenance repair hypotheses:

> "The practical problems linked to the upgrade of WOs are related to the way maintenance works are initiated, prepared and executed. The solution given to each problem must be compatible with a variety of issues. Many factors must be taken into consideration such as safety issues, the quantity of the available resources, the competence of the available technical crews, the time for the solution, and of course the cost. The WO form must contain data that will be derived from the analysis of the incident and must express the scope of work based on this analysis. [...] My point is that depending on the period of the year, the production plan, the available money and other factors, a different solution will be given to the same incident that occurs to a specific piece of equipment. An analysis of these incidents could never lead to the identification of a single solution. Besides, an analysis in the early stages of an incident usually fails. [...] You should also take into account that the WO is only a snapshot of the maintenance repair and it's difficult to take it as representative of the whole process."

Moreover, the research indicated that information flows, which could add value to the WO, disappear. For example, the RED head explained that information, which should accompany the WO for the description of the repair concept, is kept within departmental archives:

> "Yes, we keep flow charts or blueprints when we execute a job for the first time. [...] We also keep simple instructions. A blueprint with a sort paragraph is adequate. The blueprints will be used by departmental engineers and technicians. [...] We don't give these blueprints and instructions to the PD (for the WO). Besides they don't perform the job."

WOs concerning preventive maintenance tasks are in general much more complete and organized than reactive maintenance WOs, since they integrate more information flows. A PD engineer noted:

> "Preventive WOs usually contain clearer descriptions. The explanation for this is that departments have clarified what they want to do, and most of the time they execute it as planned."

The RED head also argued along the same lines:

"For example, we issue a WO for the (preventive) shaft alignment of compressor X or for the (preventive) replacement of a pump propeller and we know how many people and what kind of spare parts we need for this job."

Figure 6.3 **Unified Maintenance Work Request/Work Order Form**

NO WORK IS TO BE CARRIED OUT WITHOUT THE NECESSARY SAFETY ISOLATIONS AND PRECAUTIONS.	**Importance**
ORIGINATOR:	
MACHINE:	**LOCATION:**
TIME DOWN:	**DATE:**
FAULTS:	
INITIALS:	**SHIFT: A B C** (Ring as applicable)
AUTHORIZED WORK:	
MAINTAINER: DESCRIPTION OF FAULT FOUND	
ACTION TAKEN:	
TIME RETURNED TO PRODUCTION	**INITIALS:**

SPARE PARTS USED:							
NOT AVAILABLE:							

		SHIFT A	**SHIFT B**	**SHIFT C**
TOTAL HOURS SPENT	**SED**			
	RED			
	ED			
	ID			
	Total			

FOLLOW-UP ACTION REQUIRED:	
Production Supervision's:	**Maintenance Foreman's:** **FAULT CODE:**

Additionally, a SED engineer noted that corrective repair concepts are split in more than one WOs:

"We open a WO for the replacement of a vessel pipe because it leaks and we end up with a newly reconstructed vessel. How can you expect that the (authorised) WO could describe the whole repair? In the best case there'll be one WO requesting the replacement of the (leaking) pipe and then after sometime, perhaps a week or more, personnel will raise another (complementary) WO saying: "vessel repair"."

Moreover, a PD engineer added:

"Often corrective WOs require the issuing of additional WOs. The problem is that in the end we're not in a position to find out how many WOs were opened for a specific job."

Supervisors contribute significantly to the creation of WOs, since they often withhold information about either the authorised or the executed maintenance work. A PD engineer explained:

"Supervisors (from the other maintenance departments) are always in a hurry and don't pay particular attention to the requirement for proper completion of the WO".

Lower management responsibility was also recognised by an ID supervisor:

"When an incident is in progress and we're unsure about its nature, there's little time for such paperwork like the full completion of all the details."

The miscreation of WOs is also connected to the limited participation of OD representatives in discussions. An OD engineer said:

"The only responsibility of the equipment operators is to request maintenance of a particular piece of equipment. They're not very involved in the description of the incident. [...] When they're asked about the potential fault they give their opinion, but I don't think that operators are the kind of employees who would chase the MD in order to see whether they have recorded everything on their WOs."

Some maintenance supervisors strongly emphasized the fact that problems related to the WO are due to the involvement of the PD, which is responsible for capturing the required information. For example, a SED supervisor described the role of the planners:

"The role (of the PD) is only supportive. We tell them what we want and they make sure that this will be available on time. They transfer the message from the field to the Departments and they keep their information. [...] If WOs are not as they should be, this has to do with the lack of involvement of the PD, which is responsible for the MWOS."

In addition, a RED supervisor noted a lack of trust:

"The problem with half-written WOs stems from the inability of the PD to understand and record the necessary information."

Another ID supervisor noted:

"The planners don't understand the details of the work. They have absolutely no or very little experience and it's difficult to explain to them either the scope or the exact details of the work."

Maintenance engineers provided another perspective. A SED engineer highlighted the difficulty in convincing their supervisors about the usefulness of a working system with WOs:

> "It's not very easy to make someone who works at the refinery for twenty-six years to complete all the details on a piece of paper!".

Moreover, a PD engineer added:

> "There's little encouragement by management to use the system (MWOS). When there are cases in which we do maintenance work and we do not open a WO because the "work is not very important", how do we expect the system to produce reports? And when I say encouragement I don't mean that management will one day give the order to use the system. Much attention and care is required in order to be in a position to operate the system."

There is also limited understanding of the potential use of the WO after the completion of a maintenance job. For example, the response of the SED head was indicative:

> "As far as I'm concerned the thought of tracking costs through the use of WOs had never been an issue here, since this is a responsibility of the Accounts Department."

A PD engineer added:

> "The MWOS was intended to assist the MD in keeping track of, prioritising, planning, scheduling, archiving, analysing and controlling all the maintenance work! The refinery was using a MWOS before the 1987 revamp, but we thought that the new system would be more effective and that we would have the ability to track equipment history. [...] No, we don't record information from WOs for building equipment history. [...] Feedback on WOs isn't much, perhaps a sentence, maybe two, but no more than this, and of course not always."

However, and despite the fact that middle managers in interviews indicated consensus about the potential of WOs for the creation of equipment history, the demonstration of lack of trust was also evident. A SED engineer argued: "Our work is mainly reactive and therefore I don't see much use in the processing of historical records", while an engineer from the RED added: "It's rather difficult to imagine employees from the PD processing WOs in order to create maintenance policies or strategies!".

Finally, the introduction of IT for the support of the MWOS of the MD occurred in 1992 with the Computerised Maintenance Management System (CMMS). However, the procedure is not fully computerised. Hence, WRs are always in a paper form, whilst WOs exist both in a paper form and digitally in the isolated CMMS, which is in operation only in the computers of the PD. Therefore, WOs have to be printed before their distribution to maintenance personnel. A RED engineer pointed out the lack of appropriate ICT infrastructure, which could connect the PD with the workshops, and the influence of the Asset Register database, in addition:

> "The workshops are not computerised and technicians can't access WOs and update them with information, for example, after they've performed an in-depth inspection. [...] The problem with

> equipment identification system is also important. How can you build an effective MWOS when there's equipment without a tag number[55]? When you issue a Work Request what sort of description would you write? Sometimes we can't clarify where personnel should execute the work."

6.4 The art of planning and scheduling

Once the execution of a maintenance job, meaning a repair concept, is authorised, the planning and scheduling process begins. Planning is the identification and quantification of all required resources, while scheduling is the determination of the sequence of all involved activities for the execution of the work. Planning and scheduling requires the breakdown of the authorised maintenance repair concept for its integration and synthesis with other information concerning the availability of labour, skills, materials, tools, and the adopted repair method.

The development of a Job Plan (JP) facilitates the containment of knowledge of the planning and scheduling function. In practice, and within the MD, the JP is a document set, and is not integrated. It combines, under the auspice of the WO, a number of documents that cover various aspects of the repair, such as job instructions, job execution details, maintenance strategies, work standards and specifications. The PD head mentioned:

> "Well, yes we attach documents to the WO. Depending on the case, we attach the Permit-to-Work document or contracts. [...] The contracts contain job specifications, not job instructions. It's difficult to include job instructions. [...] These different documents (WO, Permit-to-Work etc.) are bound together by the fact that they concern a specific job, we don't make any further attempt to integrate them."

Afterwards, the JP is passed on to the other maintenance departments, which have to execute the required work. A typical integrated JP contains all or some of the knowledge categories presented in Figure 6.4.

Officially, the PD is responsible for the planning and scheduling of all maintenance activities. However, in reality, the PD is not the master of this function. For example, a RED engineer noted:

> "The PD can neither plan nor schedule, because they don't know what's required to be done, how it'll be done, and what resources are required for the job. [...] Their role is to do the paperwork."

In addition, a SED supervisor explained that the planning and scheduling function is performed traditionally by the supervisors, whilst the PD "makes the necessary arrangements", such as

[55] Tag numbers allow the unique identification of maintainable equipment. The asset register database contains the complete list of the refinery tag numbers.

fetching the Permit-to-Work document from the OD, which authorizes formally MD personnel to carry out a defined job in a hazardous environment, or the collection of contractors' repair bids:

> "Planners don't know how to perform a task, they lack knowledge about crew coordination and they can't resolve everyday work problems. [...] The acquisition of the Permit-to-Work paper is perhaps the only contribution of the PD in the execution of maintenance works".

Figure 6.4 **Content of typical integrated maintenance Job Plan**

Safety and Environmental Matters Information	Facilities Information
Permits & isolations Personal protective equipment Barriers and/or warning devices Removal of debris	Special tools/maintenance aids Drawing references Operation and/or maintenance manuals Lifting/handling aids
Sequence and Duration of Repair	**Spare Part Information**
Fault finding/diagnosis guidance Special maintenance skill requirements Special checks, readings to be taken and recorded Certification and Proving trials to be performed prior to handover to Production List of tasks to be performed in sequence order Estimated duration of each significant operation	References to required spares Indicate whether parts are replaced in situ or off-line

One evident problem of the planning and scheduling function has also to do with the determination of the relative importance of a job in conjunction with other jobs that need to be scheduled for execution. This work priority system at the MD appears to be a source of ambiguity, since it allows many interpretations. The PD head explained that lack of explicit knowledge on the criticality of the incident undermines JPs:

> "Many attempts to issue maintenance job schedules in the past were undermined by "emergency" incidents that afterwards turned out not to be so urgent!"

The execution of JPs is performed according to the perceived priority of the initial work requestor and not according to predefined criteria that identify objectively the incident's criticality. Thus, according to the existing work priority system, work requests are divided into three categories, "Urgent maintenance work", "To be completed as soon as possible" and "Non urgent maintenance work".

Another example of problems in the performance of the planning and scheduling function by the MD concerns the case of scheduled refinery shutdowns[56]. A PD engineer said:

> "Our department uses dedicated maintenance planners for the preparation of the shutdown schedule. The preparation of a schedule containing a few thousand jobs is the ultimate challenge. [...] Maintenance activities to be executed in shutdowns are known in advance; however the scheduling process had never been successful."

Refinery personnel often narrate a popular story illustrative of the problems of the PD to perform its role that concerns the "notorious" 1996 refinery shutdown, which was the first real opportunity of this department to demonstrate the abilities of their new IT tools, the CMMS and Primavera. The RED head noted:

> "The planners prepared a work schedule that collapsed within the first day and the supervisors saved the situation. We were expecting this since planners lacked the necessary experience to schedule a shutdown."

However, the problems of the planning and scheduling process at the MD appear to be much more complex, since interviews revealed, for example, that planners perform the planning function with relative success. A PD engineer explained:

> "Our planners manage to break down every authorised WO into a group of required maintenance tasks with success. [...] Indeed they can do it with great certainty for the vast majority, let's say ninety-nine percent, of the WOs. The situation is not as bad as some people want to present it. Planners can't go further than this step for two reasons. First, they lack vital information and then the supervisors change the scope of the work all the time."

Indeed, interviews with representatives from various maintenance departments linked explicitly planning and scheduling problems to the maintenance repair concept. For example, the RED head noted the occurrence of improvisational (Weick 1998; Moorman and Miner 1998) changes to the repair concept, or in simple terms, to the scope of the work, and consequently to planning and scheduling by supervisors:

> "I understand the need to define clearly, to the extent possible, the scope of the work to be done, but there's always a borderline between "technically feasible" and "worth doing" and this is the reason for which we very often change the scope of the maintenance work, while the job is in progress. [...] Usually supervisors decide about these changes. After all, they're the first to get the news from the workshop and the unit repairs. [...] The PD isn't always notified."

[56] An established maintenance practice in the oil refineries, which operate on a constant basis, requires a programmed shutdown every four years for the simultaneous execution of numerous pending maintenance works.

A SED supervisor explained that changes to the scope of a maintenance job, which occur for a number of reasons (such as wrong fault identification, the discovery of hidden failures, or the lack of spare parts) make response to actual situations difficult and planners are not able to reschedule, nor even with the use of Primavera. The PD head added:

> "With unexpected and last minute changes all estimates, such as for the time necessary for the execution of the job, are always rough, and this leaves no opportunity for comparisons with the actual figures related to the completed job."

Besides the frequent changes to the scope of the work, interviews also indicated that problems of the planning and scheduling process and of its product, the JP, are connected not only to the existing knowledge sources that support this process and to the way these are utilized, but also to the intentions of the employee group that exploits them.

Various internal and external sources of knowledge support the planning and scheduling function. Interviews with the ED engineers indicated that such sources include corporate internal operational regulations, environmental and occupational health and safety legislation, operations and maintenance manuals, national and international standards, work specifications, spare part specifications, cost information, and various databases and archives. These knowledge sources belong not only to MD personnel, but also to various other parties, such as suppliers, manufacturers, professional institutions, and governmental organizations.

However, these sources are not utilized in the same way by all maintenance departments. This is also reflected by the different treatment of JPs across the MD departments, since, for example, those at the SED are impoverished, while JPs at the ED and the ID contain much more valuable information.

First, and with the exceptions of the ID and the ED, which often, but not always, use national and international standards for descriptions of the job to be executed, maintenance personnel do not use any written maintenance strategies or job instructions, or any other similar forms for the identification of the repair method. The ED head explained:

> "The use of (national and international) standards is a common practice in our profession and our department has emphasised their use especially for safety reasons."

Thus, the ED produces enriched JPs, which contain not only the WO and the Permit-to-Work, but they also direct technicians through standards and contracts that are prepared by middle management. The ED engineer said:

> "Job specifications or even the contract itself often accompany the WO and the other required documents (for the job execution)."

The ED head added:

> "Yes, the contract shouldn't be distributed all over. But supervisors can do their job better when they have a copy with them, so we give it to them. After all, they're our colleagues, we don't want to make their life more difficult! [...] In the rare cases that we don't want them to see some financial details, we just remove these pages from their copy."

Additionally, a RED engineer mentioned:

> "When external contractors are involved in the repair, the contract accompanies the WO."

An ID engineer said about the use of standards:

> "Suppliers insist on the use of standards or otherwise the instrument guarantee is void. [...] Standards accompany the WO especially in cases of calibration, but almost every work with instruments requires calibration. [...] I can't discern the most valuable (knowledge source). Contracts, permits and manuals are all extremely important for the execution of the repair."

In contrast, the use of standards for the SED and the RED is rather limited, if non-existent, and it usually takes the form of low-level standard maintenance routines. Thus, either the lack of or neglect of knowledge sources about standardized repair methods leave much space for improvisation (Weick 1998; Moorman and Miner 1998). A SED engineer explained:

> "With standardised maintenance works, the planning and scheduling process would be much easier. Now, it's understood that the present situation is confusing since there is a wide spectrum of options between the purchasing of the spare part and its fabrication before its installation."

In addition, the SED engineer highlighted that contractual information does not enrich their JPs either:

> "We never give contracts to supervisors along with the WOs. [...] Of course, it's a way to introduce job specifications, but contracts also contain other kinds of information (such as cost) and we don't want them to end up in the wrong hands."

Additionally, the same happens with departmental reports. The RED head noted:

> "When reports are produced, they're used only by engineers, we don't distribute reports to technical personnel."

Consequently JPs in both the RED and the SED are very simple. A SED supervisor said:

> "All we need is the WO and the Permit-to-Work. All the rest is a responsibility of the technicians. [...] There's absolutely no need for attaching job instructions to WOs, we know what to do."

Interviews also demonstrated cases of relative neglect of documents with maintenance strategies that could guide the repair method. The response of the RED head was indicative:

> "Of course we maintain our equipment with strategies (in mind), but they aren't written in a standardised form. Supervisors and senior technicians have been practicing these techniques for many decades and they know them by heart."

However, middle management seemed to understand the potential role of a database with written maintenance strategies. A SED engineer noted:

> "I believe that it would be very good to have all these instructions and strategies in written form. It would provide newcomers with material to study before their exposure to the field."

Furthermore, a RED engineer emphasized a basic trait of the engineering culture (Schein 1996), namely safety:

> "These documents (strategies) would help supervisors and technicians understand the established maintenance policy for each equipment category. As an engineer I can tell you that it's also a back up for all engineers. In case of an accident you can always say that the work instructions were written. Our responsibility ends at this point."

Besides knowledge sources concerning the method and the specifications of the repair, the planning and scheduling process often bumps into obstacles associated with the condition of departmental databases, and especially the Asset Register Database[57]. This database, amongst other things, provides information about the exact repair location within the refinery, the venues of which occupy a few square kilometres, while it supports the creation of reports. The AR database of Petrochem consists of approximately forty-two thousand entries of maintainable items and utilizes historically an alphanumeric identification system based on international standards. It is kept in the CMMS and its management is a responsibility of the PD, whilst its utilization is associated with the MWOS, and in particular with the issuing of WOs.

An examination of the AR database, combined with interviews, highlighted the existence of a number of fundamental problems associated with the quality of its data and information (Davenport 1997; English 1999; Eppler 2003). These indicate that the database does not support the planning and scheduling process particularly well. For example, there is lack of the necessary database maintenance activities. A PD engineer noted:

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[57] The Asset Register (AR) is a common name of the list of all the plant and equipment that require maintenance. The AR identifies uniquely the various assets supported by the MD through a numbering system accompanied by very precise text descriptions of the named assets, structured in a hierarchy. The AR is the basis of all information systems used to report asset performance, maintenance failures and costs or even maintenance history.

> "No, the procedures for the maintenance and the update of this database aren't followed. [...] We haven't appointed somebody responsible for (equipment) registration. [...] This is supposed to be a collective (departmental) responsibility. So, everybody from the department can register equipment in the database".

Another common problem concerns the ambiguity of the database entries, which sometimes lack precision and accuracy, while some other entries are incomplete. A PD engineer explained:

> "Not every equipment piece is tagged, so the database doesn't contain all equipment. [...] I don't remember when was the last attempt to tag the equipment. Maybe more than ten years ago. [...] When you don't know the exact number of installed equipment you have, you can neither manage it effectively, nor can you produce reports. [...] We definitely need to adopt a certain equipment classification."

Furthermore, sometimes information is unreliable, since changes with installations of additional equipment or even decommissioning of equipment escape the database.

The polymorphic nature of the AR database is also an additional obstacle to the planning and scheduling process, since besides the AR database of the PD, every maintenance department with the exception of the WD, has created its own AR. The format and the quality of information of each AR varies greatly and depend mainly on their use and management. For example, the SED head explained that his department's AR database contains in electronic format only some of the main pieces of equipment:

> "The rest of the equipment, ten to fifteen thousand equipment pieces maybe, is listed on hard copy. [...] These lists were created at the beginning of 1990s. [...] We integrated the lists of equipment provided by suppliers after the (1987) revamp. [...] They have never been updated. [...] These equipment lists can't be integrated into the CMMS AR as they are. Some units were decommissioned. Some other units have been added. In many other cases the piece of equipment that exists in the list has been replaced. [...] We have never used them either. The engineers and the supervisors know very well where these pieces of equipment are located in the field."

Furthermore, a SED engineer pointed out that the fact that their department does not produce any sort of reports and does not use performance indicators - not for departmental, nor for inter-departmental use, and this contributes to the non utilization of the AR database.

In contrast to the situation in the SED, the ID utilizes and maintains an AR database using an MS Access application. The department head explained:

> "We created a list with the existing instruments more than eight years ago. Its creation was absolutely necessary because of the number of existing instruments. They are twenty-nine thousand if I am not mistaken. We couldn't manage them without a database. And you know that we change instruments very often. [...] One basic reason is that when instruments' technology changes, and it

does change very quickly, the suppliers don't provide spare parts (for old instruments). Many instruments nowadays are digital and it's not easy to fix them, so we buy new ones. The other reason is that the petrochemical industry wears out the instruments quickly. We must have a system to know what sort of instrument is in which location."

Furthermore, the ED AR database is also in excellent condition, since it contains valid information that is regularly updated and managed. Thus every database entry corresponds to an actually installed piece of equipment out in the field. Besides, the ED produces regular internal reports for monitoring the performance of their equipment and this offers an additional reason for maintaining its equipment database.

Additionally, another major database, the CWMS spare parts database, obstructs the planning and scheduling process, according to an audit performed by consultants, as a result of similar data and information quality problems.

During the research data collection period there was also an on-going project aimed at the transferring more than ten thousand diagrams from Technical Archives Department into electronic format for the creation of the Electronic Diagrams Database, which could in future support the creation of more complex JPs.

Besides the role of databases as sources of knowledge for the planning and scheduling function, the contribution of various reports is significant. For example, the ED engineers compile collected on-line information from all over the refinery, enabling the monitoring of the condition of electrical equipment and in particular of all pump motors. This information, which is displayed on a panel established in the ED offices, produces internal reports with performance indicators. These guide equipment replacements and repairs by clarifying the repair target. An ED engineer said:

"We've been producing performance indicators on the (electrical) equipment availability for many years. [...] Reports with performance indicators are used mainly within the department. [...] Nobody has asked us to produce them. We do it because it makes our job easier. [...] We often attach (performance indicators) reports to WOs. [...] The answer for this is simple. The technician has to perform a repair, hence along with the WO that describes the authorised work we give him the Permit-to-Work, one or two standards for the repair and the report that helps him adjust the performance of the (new) equipment accordingly. [...] (In other cases) we know that the Warehouse has run out of spare parts for motors and we know that the motor is bound to fail (something evident from the report). We order the spare parts before the repair."

Similarly, the ID uses ICT for the collection of explicit information about the condition of many critical instruments. The ID head noted:

> "We collect online information and we monitor the performance of many digital instruments."

The compilation of reports by the ED is achieved through the utilization of knowledge existing in manuals and other documents. This knowledge facilitates the processing of OD data collected with sensors and instruments that replace face-to-face interactions with the equipment operators. An ED engineer explained how ICT promotes virtual interactions with the OD:

> "The creation of the panel started approximately 6 years ago, in an effort to cope with the increasing complexity caused by the expansion of the refinery and the development of the substation network. [...] The idea for the construction of the panel was not entirely mine. It had been discussed in the department many times. Some colleagues and I had heard about something similar. We decided to try it. I volunteered and I was responsible for the project. [...] The panel was constructed with the use of local resources. [...] It was much cheaper to construct it this way and it was a good opportunity to train my technicians. [...] Of course, we have control rooms for the operation of the electrical equipment. This panel isn't for the operation of the equipment. It provides necessary information so that we can organize the equipment maintenance on time, before the equipment breaks down (completely). However, even in case something breaks down, we pump out useful information that allows us to determine what possibly went wrong and how to correct the damage. [...] We get the necessary data using an interface with the DCS[58] (established in the OD control rooms) that sends us information about the operating hours of each motor and its efficiency factor. [...] There's also an established system that transmits information from the substations through the refinery optic fibres network. [...] The panel collects information that was difficult to be acquired from the operators in the old times. [...] Operators had that information but they needed to prepare reports and give them to us, but they always kept finding excuses for not doing it."

However, the utilization of reports in the planning and scheduling process by the ID and the ED is not indicative of the situation in the MD, since interviews with employees from the SED, the RED and the PD revealed that these departments have a different approach. Hence, the SED head explained that they do not synthesize reports:

> "We get reports with measurements ready from the Inspections Department. Then we just take our course of action."

A RED engineer pointed out that while they monitor the performance of specific equipment groups, similar to the ED, they do not synthesize this information:

> "Yes, we monitor the performance of compressors, but we don't produce any further reports."

[58] IT application for the control of the operation of the refinery production units

Moreover, the same engineer noted about reports from the PD:

> "The CMMS has never been used for the production of a single report. [...] Historical information about repairs is provided by supervisors and technicians, but you understand that they don't remember every detail."

Besides the contribution of reports with performance indicators, interdepartmental or interdivisional reporting at Petrochem and the MD appears to be rather weak not only in relation to planning and scheduling, but also with respect to all maintenance activities, with the exception of financial reports that are produced on a regular basis. The ED head explained:

> "We have to report on our expenses frequently and we usually do it weekly".

Middle managers explained that the Division is not familiar with this style of communication and that top management does not make decisions based either on the CMMS or on other reports. Indicatively, the WD head explained:

> "We don't produce any sort of reports because we've never been asked to do so. Besides, management doesn't make decisions based on reports."

The ID head said:

> "CMMS reports had never had any impact on decision making. [...] I think that the morning meeting (of the department heads) has more influence on decision making than any report."

However, the ID head also explained that inter-firm communication via reports is pretty standard for them:

> "We often report instruments performance to suppliers via a standardized process."

Moreover, the RED head noted about reporting interactions with the OD:

> "No, we don't produce reports for the OD, they should produce reports for us, but they've never done so."

The weekly report of the Inspection Department, which summarizes the findings of proactive maintenance measurements, is one of the few examples of compiled reports that influence the planning and scheduling process, along with the maintenance backlog report that has gradually replaced the issuing of the daily and the weekly maintenance schedule. The PD head said:

> "Almost everyday we produce a report on the maintenance backlog. This is the most accurate way to monitor the progress of departmental works."

Furthermore, the planning and scheduling process is facilitated, as interviews with engineers from the ED, the ID and the RED indicated, by an additional source of knowledge that accompanies the JP. A RED engineer explained:

> "Very often we produce small feasibility studies or write maintenance manuals. These activities occupy a significant amount of an engineer's time. [...] It's a tedious task but absolutely necessary. These documents contain the essence of our job."

However, and besides the issue of knowledge sources that contribute to the creation of a JP, interviews and discussions with middle and lower management pointed to the importance of roles responsible for the collection and the synthesis of this knowledge. According to official sector Maintenance Benchmark Reports, two PD positions normally perform these two roles - the Maintenance Coordinator, who collects explicit information and the Technical Engineer, who integrates it within the JP. Notwithstanding, interviews showed that within the MD these two roles are performed by the supervisors of the maintenance departments, since the PD does not have maintenance coordinators and technical engineers. For example, an ID engineer explained that the departmental position of the Crew Coordinator, not only performs these two roles, but also covers JP weaknesses, since JPs rarely contain scheduling or other information related to the sequence of the tasks to be executed:

> "It would be pointless to try and standardise the priority and define a preset sequence of the job tasks. We always make last minute changes. [...] Yes, this is a responsibility of the Crew Coordinator. [...] This position is at the level of the supervisor and is responsible for the scheduling details."

The ID head also explained the importance of the synthesis of JPs for his department:

> "The function of the technical engineer (in the PD) would remove valuable information from the maintenance departments, while there's no evidence that it could help the PD. [...] The preparation of the JP is an important function for us. We define the details of the repair. I don't think that it would be feasible for us to proceed with the execution of the job if we weren't involved in the preparation of the JP."

Moreover, the ID head highlighted the importance of sources of explicit knowledge, such as maintenance strategies and databases, and argued that the technical engineer function in the PD could never be successful, as long as these knowledge sources are not ready.

Additionally, the role of the technical engineer within the ED is performed by engineers who exploit existing knowledge sources in combination with a maintenance methodology, called Equipment Condition Monitoring, and suggests the monitoring of some basic parameters of the equipment operation. Then, these parameters are further processed according to formulae and instructions described in standards, manuals, handbooks for the production of the reports and the forecasting of the imminent faults. An ED engineer explained middle management's actions:

> "The most important step was the panel, which brought the signals (from electrical equipment) into our office. The rest is quite straightforward. When you see that the performance of a motor declines

> day by day, you've got an indication that something's going wrong. [...] The methodology is a powerful tool in our hands. We can predict with a high degree of accuracy a forthcoming failure. [...] We don't know everything by heart, we get advice from manuals and standards, but more or less we know what to expect."

Condition Monitoring allows the ED engineers and supervisors to plan and schedule departmental activities. An ED supervisor said:

> "Condition monitoring techniques are very important for the organization of our work. Knowing when to act allows us to achieve miracles. The panel helps the department plan and schedule maintenance works and especially those that require the removal of the equipment, which are usually the most time-consuming."

ED engineers also create archives of performance indicators reports, which contribute to the measurement of the effectiveness of adopted maintenance practices. The ED head explained:

> "We've had electronic archives since the establishment of the control panel. [...] It's good to know that there's a consistent archive. [...] Although we don't use it all the time, we can make comparisons before and after important changes."

These reports are often disseminated within the departmental boundaries and especially amongst the department head and engineers. In a limited number of cases, these reports are disseminated across departmental boundaries, either for the justification of a new investment, or due to a manufacturer's request about the performance of its product. Indicatively, the same engineer mentioned:

> "Petrochem isn't an official member of OREDA[59], but we (the ED) have some infrequent correspondence with them and we have to give them some (performance) reports so that they help us with our questions."

Middle managers at the ED are also involved in the preparation and execution of departmental Job Plans. An engineer explained:

> "We choose what has to be done, and how. Our supervisors support our decisions; since they're well educated they're in a position to understand our intentions. [...] Their support is focused not only on the job execution, but also on the organization of the work, and this collaboration pays off. [...] The good thing is that when we (middle management) are organized we help technicians execute their duties more easily."

[59] An international organization that collects and processes equipment reliability data from petrochemical industries.

In contrast to the ED and the ID, other departments, such as the RED and the SED adopt a less proactive approach to the planning of a scheduling function. For example, a RED engineer explained how departmental supervisors perform the scheduling process:

> "Supervisors move around and talk to everybody. They collect information and estimates about the work. Then they just proceed with the scheduling of the required tasks only with the use of their wireless telephones. [...] Supervisors don't use computers and don't like paperwork."

A PD engineer pointed out that this role emerges naturally:

> "On the one hand, they understand and control the work scope, which is not recorded properly on our WOs. Then, they have estimates of the required resources, something totally natural, since they control the crews and can find them whenever they want. They also know the location of the work and they're in a position to understand the priority of the work. [...] And all this information isn't written anywhere. Supervisors just have an advantage because they have access to the (information) source. [...] So the fact that after all they control the scheduling function within the refinery is not so surprising!"

Departmental supervisors, and not the PD planners, also assign and distribute JPs, which in their simplest form comprised a WO with a Permit-to-Work, to the personnel. A SED supervisor explained:

> "The PD personnel can't assign JPs to technicians. They can do it only through us. [...] They can't do it simply because they don't know what skills people have. [...] If they had the required personnel database, perhaps they could do something."

Moreover, the same supervisor added:

> "Depending on the repair we select the team to be involved. [...] Sometimes we want to have the most competent workers, because they'll recognise the potential risks in the repair and they'll also recognise a case of wrong fault identification quickly. Other times we pick someone just for training reasons."

Thus, within the established planning and scheduling framework, the role of the PD is limited. In fact, the PD is involved primarily in fetching the Permit-to-Work document from the OD, the frequent issuing and distribution of the maintenance backlog report, and transferring the required contract or invoice between the supplier, the contractor and the other maintenance departments. The PD head described the transactional role of his department, which reflects the existence of collective interactions - neither created nor regulated by PD employees:

> "The involvement of the department in the scheduling process concerns the daily distribution to the other departments of the maintenance backlog list. Supervisors undertake the rest. [...] The Permit-to-Work is also a departmental responsibility. Planners go to the OD with the issued WO and they

get the permit. We don't have any other involvement than this. [...] We're also involved in the transferring of contracts, invoices and purchasing orders."

The PD head added:

"Planners aren't trained on maintenance planning and scheduling techniques. They're only trained on how to use the planning and scheduling software. [...] In the past we had tried to take care of this. We'd sent personnel to attend seminars, such as WO planning and scheduling, materials planning, or project planning."

Hence, it is not surprising that interviews with engineers and supervisors recorded arguments that demonstrate lack of trust as to whether the PD could and should incorporate the maintenance coordinating and the technical engineering functions, and whether these positions could facilitate the creation of an integrated and applicable JP. For example, a SED engineer stated, concerning JP preparation by the PD through the use of the CMMS:

"It's difficult for the PD to perform these two functions. I've told you that repair conditions are rarely the same so the PD will have to produce different JPs all the time. People from the PD will rarely find the same JP in their CMMS database. [...] Besides, the problem for planners is that they aren't closely related to the job execution. Feedback on the produced JP through the return of completed WOs could also be slow. Of course they can update the databases of the CMMS to produce better JPs in the future. However, this improvement will occur very slowly and I don't think that technicians and supervisors will be so patient. They can forgive one or two mistakes in the preparation of JPs at the beginning, but technicians will start ignoring the JPs if they don't change. [...] Don't forget that the past is full of examples of failed planning and scheduling attempts."

Even the ED personnel reacted to the possibility of the preparation of integrated JPs by the PD, however moderately. The ED head noted:

"We'd prefer to maintain the functions of the Maintenance Coordinator and the Technical Engineer, because we'd be able to control them more effectively. However, we could also support such functions at the PD. [...] Standardization is usual in electrical maintenance activities so the preparation of an integrated JP doesn't make us uncomfortable."

Nevertheless, the ID head also seemed to understand the need for the creation of an integrated AR database that could assist complex and standardized JPs. This was reflected in his response during discussions, when he suggested the utilization of ID personnel for the database creation, reflecting at the same time the lack of trust towards the PD. The ID head mentioned:

"The PD should have the responsibility for the creation and update of the AR. Although, I believe that in my department we have the necessary expertise in order to do that. The AR consists of both electrical and mechanical equipment, the instruments are divided in two major categories: mechanical and electrical. Hence, I have both mechanical and electrical engineers who can create, validate and of course manage the AR. [...] The PD doesn't have the necessary expertise to do it (the creation and maintenance of the integrated AR database) for the MD. First of all they're not trained and I believe that they won't be able to create the AR required for the ID. Even if we assume that they manage to create it, they'll have to create different lists for the ED, the SED and the RED. These departments have different working requirements. So it'll be very difficult."

In addition, interviews indicated that not only an upgrade of the role of the PD, but also the enhancement of JPs require a solid vision and direction, since for example the JP is not well-established, nor is its value understood by the MD. The PD head noted:

"The preparation of integrated JPs for effective planning and scheduling is new knowledge to us. The Division had never before attempted to prepare integrated JPs."

However, a SED engineer stressed the need for direction:

"And what do you do after the combination of so much information about safety, policies, (maintenance) strategies, spare parts, skills and job specifications? Will the technician do his work better? It's doubtful. Or do you expect that the PD will process (completed) JPs? They'll not do it either. There's no point in spending much time when we have no expectations of it."

A PD engineer added:

"Training isn't enough if we want to change this situation. We also have to understand why we have to use a different system (in which supervisors should not cope with the scheduling function), when the refinery has been operating perfectly well for many decades without it."

A SED engineer also highlighted the lack of commitment dooms planning and scheduling attempts and noted that there is also lack of trust that the CMMS could enable or support the creation of reports useful for maintenance works. The SED engineer explained that this has to be overcome by showing that the CMMS could provide valuable help in the planning and scheduling process in common maintenance cases, and therefore a vision within the MD should promote standardisation. The engineer also added that this is necessary since the CMMS would probably fail during rare incidents because their rarity would not allow the execution of a similar work that would verify the rightness of the decisions.

A SED engineer indicated that direction should focus on databases and their utilization:

"The CMMS in order to operate, requires to be fed with data and information and people must be adequately trained. Only then, and if people from the PD acquire the necessary skills, which will enable them to use the database information for the analysis of maintenance works, will they manage to control the maintenance plan with the CMMS."

However, such an attempt would not be effortless, since estimates revealed that the refinery CMMS could only operate effectively if it included a database with approximately fifteen thousand completed and standardized JPs. Only then would planners and other maintenance personnel have available a representative set that could cover the vast majority of maintenance repairs. The PD head was positive about the standardisation of JPs:

> "Standardised JPs would enable the PD plan and schedule. Our performance would improve if we created an initial database with JPs and then started improving it with updates and data collection."

However, all other department heads, engineers and supervisors did not share the same enthusiasm with the PD. Middle management considered preparing fifteen thousand JPs ambitious. Moreover, responses both from the SED and the RED focused on the issue of lack of sources of explicit knowledge for the necessary preparation. A RED engineer explained:

> "We have technical manuals to pump out data. We also have drawings, but they need to be validated. Notwithstanding, our information base lacks historical data, spare parts lists, and instructions and information regarding job execution. Hence, the preparation of (standardised) JPs will not be an easy job for us."

Finally, the PD should also follow the example of the ED, which created virtual interactions for the acquisition of data from the OD, overcoming past experiences. A WD engineer noted a lack of ICT support:

> "Five or six years ago there was an interface (between the CMMS and the CWMS). The interface had been developed by the PD head. He's very competent with computers. The interface allowed the PD to extract data from the CWMS and to check spare parts availability in order to plan and schedule. [...] The interface couldn't allow online stock availability checks, but that wasn't the problem. Planners had problems in identifying what was required for a work order. In cases in which they could identify what was required they couldn't find it because of classification problems (of the spare part database). After a few months the interface was abandoned."

The PD head saw this as demotivating:

> "We intended to create an interface between the CMMS, the production scheduling system and the accounting system, but after the disappointment with the (warehouse) interface we cancelled our plans."

6.5 Executing maintenance work

After the planning and scheduling of maintenance works, the maintenance personnel continue with their execution. Both the refinery size and its technological complexity provide numerous job execution opportunities for personnel, since the MD maintains more than one hundred thousand pieces of equipment, while the PD archives verify that each month they complete approximately one thousand corrective and preventive maintenance works. A PD engineer noted:

> "Well, the vast majority of work requests concern routine tasks. [...] For example, five percent of the monthly workload concerns the cleaning of pump filters and another two percent the oiling of pumps. [...] They aren't difficult tasks but they require some time and coordination of resources. [...] If you consider that daily we have (on average) a workload of thirty to thirty-five work requests, you should expect that one of them is either very rare or it occurs for the very first time. [...] We also have three real emergency incidents per week."

The execution of preventive and corrective maintenance works is based on the JP. A RED engineer explained the reasons for compliance with issued JPs:

> "That's the purpose of the JP, to define the work to be done and to ensure that the necessary permits have been issued. We avoid the execution of works that aren't covered by JPs [...] mainly for safety reasons. If something goes wrong and there isn't a Permit-to-Work issued then the situation is very bad. [...] This often causes delays because personnel stop in order to raise a new work request because when they work at the equipment, they bump into something else."

The execution of the JP justifies the maintenance repair concept. An ID engineer noted:

> "The (work) execution is your chance to test your knowledge in practice and see whether your preparation was adequate. [...] In cases in which we've erred about the reason of the fault then usually all preparations are wrong. If the fault identification process is right then the deviation in resources is not such a big problem."

Moreover, the ID engineer linked job execution with experiential learning:

> "Well, if we realize that fault diagnosis was wrong, then in the next similar incident the wrong hypothesis will probably be excluded very quickly! [...] Yes, personnel have a very good, and sometimes terrifying, memory when it comes to such cases!"

A RED engineer indicated the influence of time urgency, which appears mainly in reactive maintenance, during the job execution:

> "When we're in a hurry, we're bound to make mistakes, which we realize during the execution (of the work). [...] We're not always in a hurry because of the urgency of the incident. Very often top management pushes us to complete the repair within a short time because of production schedules. [...] It's not unlikely that in such cases we either discard the equipment and we install a new one, or we provide a temporary solution that buys us some time. Experience has shown that decisions under pressure are more often bound to be wrong."

The repair execution sets in motion a multi-actor organizational routine (Cohen and Bacdayan 1994) in which specific patterns of organizational actions and interactions become evident. Supervisors play an important role in this organizational routine, since they connect the administration with a number of work executing communities, including their autonomous teams. An ID supervisor pointed out:

> "The appointment of the tasks involved in a JP to crews and technicians has traditionally been our responsibility."

A SED supervisor explained:

> "You have a job that requires the selection of a welder. And you know that almost everybody in the department can do this job, but not all of your technicians are certified for all types of welding. [...] Obviously the work quality varies significantly. [...] In general, work quality is good and acceptable, but you can choose between good and excellent workers. Then what do you do? You have to assign the tasks of the daily JPs to your workers. [...] We (supervisors) decide which one will do what. Nobody else. [...] According to the case we make a selection with criterion that the skills of the worker should match the difficulty of the task."

Moreover, a RED engineer said:

> "In the end every member of the crew undertakes responsibility for a single task. And they start working on it. [...] They work either at the bench of the workshop or at the unit when the equipment isn't removed from its position."

Furthermore, the SED supervisor noted that besides the allocation of tasks to personnel, his role involves the coordination of overlapping maintenance tasks in order to make a good use of existing resources. The same supervisor explained that lower management barely touches tools, since they usually coordinate two or three crews simultaneously with the inspection of new faults, with the support of the wireless telephones, technical drawings and blueprints.

A RED engineer highlighted the autonomous action of supervisors:

> "Well, once supervisors get the WO and the Permits-to-Work they're hard to find and you can only trace them with the wireless telephone. They move on to the execution immediately. [...] The funny thing is that they may suddenly appear in your office after two or three days with a new WO and claim that something new appeared during the job execution, for which they only want your signature! [...] Very often they even forget to report the completion of the job to us and this is not a joke."

On the other hand, discussions and interviews indicated that middle management contribute to the job execution in a different way, that is, by producing knowledge on the organization of maintenance repairs. Therefore, middle management remain mainly in their offices. An ID engineer explained that middle management are concerned "with enacting liaisoning" (Nonaka et al. 1994):

"We support the work execution but we aren't standing, supervising the crew all the time. We mainly approve decisions that are usually taken in the field or the workshop. [...] For example, the supervisor asks us to push other departments or to contact suppliers and contractors."

An ED engineer added:

"The role of the engineer becomes more evident towards the completion of the job. The most difficult part of the job is at the end when the efforts of several people enter a stage of integration. Then, when the big picture is more visible, we step in - either for the final approval or to suggest some corrective actions. [...] We make sure that the repair progresses according to the desired specifications. [...] We use standards, previous measurements and manuals, which help us decide. But before we go out to check we have to know them very well. [...] The job isn't always routine, we have to consult these studies often."

In addition, interviews with engineers from the ID and the RED revealed that middle management often utilizes legislative criteria and the refinery's internal regulation for the assessment and the coordination of the executed work.

Notwithstanding, the PD personnel do not participate actively in the interactions concerning the execution. An engineer from this department expressed his disappointment:

"Unfortunately contact with supervisors after the job has started is limited."

The maintenance job execution organizational routine within the MD often involves systematic and emergent experimentation and simulation. Furthermore, discussions and interviews indicated the emergent nature of experimentations within the MD, which simultaneously deprive the establishment of central coordination under the auspice of the PD. The SED head explained:

"They (PD) are not in a position to record and manage experimental modifications now. They need adequate training in order to be able to understand at least the basics of the equipment. Besides this, another problem is that modifications, especially small ones, take place as the maintenance works are in progress and they are controlled with difficulty. An intended modification is a whole new project, either a small or a big one. Such a modification can be controlled. What happens when a technician and his supervisor find out during the repair that if they modify one spare part the equipment may have better performance? You won't have many other similar opportunities to take advantage. [...] With trial-and-error we achieve some improvements."

A RED supervisor noted:

> "There's no maintenance without trial-and-error, it's fundamental, everybody knows it, everybody applies it."

But the RED head cautioned that experimentation is not always successful:

> "Of course it isn't always successful! I can tell you a thousand success stories, but I can also tell you as many unsuccessful stories in which engineers and technicians spend hundreds of hours attempting to find a solution to a problem and finally throw out the equipment and replace it with something new. Such experiences are part of the game and are very useful. In fact it's very rare to achieve a perfect solution from the beginning."

Management encourages individuals that pursue any kind of experimentation. Unit and equipment modifications, which are known as "patents" in refinery working language, are indicative cases of idiosyncratic experimentations performed by maintenance personnel. These modifications, which can either be temporary or permanent, require extensive experimentation in order to ensure the continuous and safe operation of the unit. The SED head provided another example of a rather simple temporary solution that requires "trial-and-error" experimentation:

> "When we have a pipe leakage, we don't necessarily stop the unit in order to repair it. Depending on the fluid that leaks we put some sort of elastic bandage to stop it temporarily until the production schedule allows a proper resolution. [...] It may sound easy but this kind of solution requires many attempts for an acceptable outcome to be achieved."

Experimentation often results in permanent solutions and in the creation of know-how for daily operations of the refinery. The SED head explained how experimentation assists adjustments to the local operating needs:

> "Some (equipment) modifications took place because we wanted to increase the initial unit capacity. Therefore, we changed pieces of equipment with similar of larger capacity. In many other cases however we have constructed our own patents that improved the equipment performance. Other times, we removed pieces of the original design. In other cases we added pieces of equipment, which we knew had improved operations in other units. There are also cases in which we constructed new spare parts. [...] For example, we experimented by adding a strainer or a demister. This is of course a simple example. We did it because we've seen that we would avoid damages and repairs at later stages of the refining process. We've also removed equipment pieces that were placed by the unit constructor. Units are designed based on assumptions from the operation of foreign refineries. However, the local conditions are much different because we may use different types of crude oil, not from the Northern Sea, but from the Middle East or from the Caspian Sea, so we have to remove a strainer because it would make the process more difficult."

The SED head also noted: "These modifications have undergone a trial operation period and some necessary tests", while he explained that technicians conduct these experiments both in the workshops and at the units.

The SED supervisor provided an example concerning the replacement of a particular type of pipe by another one, which was corrosion resistant:

> "When you face the same problems all the time for twenty five years, someday you wonder yourself what's going wrong and how it can be corrected. [...] We had many problems with a very long pipe that used to leak all over its length. Almost every two weeks we had to change parts of the pipe. [...] We (supervisor with the crew) decided to take three different types of pipe and replace specific parts of the old pipe. After six months we were in a position to say which type was better. [...] We replaced the whole length with this pipe and since then we don't have any other problems."

An engineer from the same department added:

> "Ever since, departmental supervisors insist on using this type of pipe almost everywhere! I don't say that it's not a good solution, but it's an expensive one."

The RED head highlighted that even experimentation in non-maintenance activities facilitates the embodiment of new technical know-how:

> "The trial period after the construction of a new unit ensures its safe operation. [...] Personnel judge the result of the work and understand how the operating and maintenance instructions (provided by the contractor and the manufacturer) combine to the local environment and maintenance practices."

The assistant maintenance manager explained that successful modifications become part of everyday working practice with their application and the assistance of lower management:

> "Supervisors are those who propose the modifications to engineers and those who make technicians practice on them."

However, experimentation is usually limited by departmental boundaries. A RED engineer noted that:

> "We try things very often, but these efforts involve only departmental personnel. [...] No, the organization of experimentations with colleagues from other departments isn't frequent. [...] The only case that comes to mind concerns the involvement of personnel with people from the ID, when they want to test the operation of new instruments. And that's it!"

The same engineer indicated that in this case supervisors make the arrangements:

> "Instruments tests are arranged between departmental supervisors. They tell us that they want to test their instruments, and our supervisors arrange when it will be done and other details."

Besides experimentation on equipment, the maintenance job execution routine often involves simulations, which facilitate a number of activities, such as equipment calibration. The ID head explained the use of simulation packages in the establishment of new instruments:

> "The establishment and operation of an instrument require lots of experimentation. [...] (Instrument) suppliers are very interested in these tests and they ask us to report problems in order to correct and improve their products. [...] Some of them have standardised procedures for the extraction of results about the instruments' operation. With some others, who are less organized, we discuss problems over the telephone. [...] We use simulation packages very often either for the calibration of the instrument or in order to have in mind how it's bound to operate before its installation."

Nevertheless, ID engineers do not only use standardised simulation packages, but also create their own software applications that assist tests. The ID head confirmed:

> "Yes, there are MS Access and Excel applications in which (departmental) engineers keep information from conducted tests with instruments. [...] They usually keep operational data. [...] They evaluate the performance of the instrument with these tests. [...] You know there's no other way to decide whether next time we'll buy the same instruments series or something new."

Simulation packages within the ID were introduced by middle management. The ID head explained:

> "In the early 1990s and with the gradual transition from pneumatic to digital instruments, it was obvious that we had to adopt a different approach about instrument maintenance. That's what we did. We first got computers and along with them the first applications for instruments. [...] We (engineers) proposed this modernization. [...] We were also among the first to learn how to use computers. [...] The education of (departmental) supervisors on computer use followed after a while."

Moreover, the head also added that departmental engineers directed these simulations towards specific instrument groups:

> "We perform simulations for a variety of instruments, but we can't do it for all of them. We focus on the most expensive, on the most critical or on those, which appear to have frequent problems. [...] Usually we indicate which instruments should be examined by the supervisors."

The simulations are performed by well-educated departmental supervisors. One of them explained:

> "We spend much of our working time, let's say a third of it, on the computer monitoring the performance of online instruments and running packages. [...] We visit the crews daily, but this happens usually in the morning, and then we return to the office. Only the crews' coordinator stays at the workshop almost all day. [...] Simulation for instruments requires a lot of time, because we examine many different variables for each case. More or less all departmental supervisors are

involved in this simulation process. [...] The benefits from this (simulation) are many. [...] For example, you can see the performance of one instrument and compare it with the performance of other similar instruments. If you're experienced enough you can understand whether an instrument operates better than instruments from different suppliers. You can do many things provided that you spend the necessary time to collect data."

The supervisor also pointed out:

"We've been simulating instruments performance for about ten years, so data (in electronic format) is available. Even in cases in which data isn't available we know how to collect it."

Another departmental supervisor explained the participation of engineers in this process:

"Simulation is not their main responsibility, but they often spend much time with us in front of the computer. [...] They can run these applications on their computers as well."

In fact engineers are the users of the simulation results. An instruments engineer explained:

"The supervisors are much more involved in the simulations than us, but we're fully aware of what they're doing. [...] We utilize these supportive results (from simulations), when we have to prepare a feasibility study or some other study."

The same engineer in a demonstration of trust noted:

"Colleagues (supervisors) are very good at the use of simulation applications and their work is very important for the department."

However, and besides experimentation and simulation, which often, but not always, form an important part of the maintenance job execution routine, the routine can be characterised either as preventive or as reactive, depending on the repair concept.

Usually both the ED and the ID systematically execute JPs for preventive maintenance. One reason for this is that they are based on the acquired relevant preventive maintenance skills (Zander and Kogut 1995). For example the ED head the noted:

"Personnel use preventive measuring techniques and methodologies for motors. [...] Besides the data collection panel, which provides only online information, a variety of measurement techniques help us identify the most likely cause of the damage and estimate when the equipment will fail completely. [...] For example, if we receive a signal that a motor has low performance, we perform oil analysis and electrical measurements on its circuit. Depending on the criticality of the motor we may apply a number of other more specialized techniques. [...] We have the skills to perform all required measurements. The Motors Crew collaborates with other departmental crews and when they have the results ready they decide on the repair. [...] Nowadays, such repairs are routine work and supervisors take care of them."

The same head also explained:

"No, not everybody has the same skills, there's some sort of specialization. [...] Each technique is known only to a group of employees."

Furthermore, the ED head described the formation of preventive maintenance approaches in his department:

"The development of a preventive approach is a process that lasted many years and had many drawbacks, but it kept going thanks to the persistence and the initiative of some people who introduced the necessary technology when the conditions where mature for the refinery to accept it. If you would discuss such things before 1995 then everybody would probably ignore it. In the second half of the 1990s the personnel and the engineers, believed in the value of this approach, but the most important factor is that they believed they could understand it and handle it. I don't think that the conditions are mature for other departments. [...] Take the SED for example. We had the advantage of managing to collect our information by connecting many kilometres of cables. The SED isn't in the same position with us. Not only because their technology doesn't allow such connections easily, but also because their personnel isn't as educated as ours."

In addition, the head explained that the gradual formation of preventive maintenance routines is connected to the department's informal maintenance policy and its history:

"The daily working life of the electricians was not very easy the first years after the (1987) revamp. The department head had decided that we should follow instructions and standards to the letter. [...] These instructions imposed the periodic maintenance of all (electrical) equipment. We treated the application of standards as a necessary evil. [...] The situation got worst with the addition of the new units of the substation network (at the beginning of 1990s). It was about that period when the department realized the necessity to adopt a more organized system. At the same time it became more evident that periodic maintenance could ensure the protection of important equipment categories, but for some other kinds of equipment it wasn't so effective. [...] For example, we used to spend much time on the inspection of equipment that didn't have problems. It's true that preventive maintenance requires much more resources than required in other cases. We had, on the one hand, technicians and supervisors complaining that WOs for inspection were meaningless and, on the other, that other important tasks were left behind. The most important step for preventive maintenance occurred when we (engineers) decided not to give up the effort (...) and to differentiate from the suggested instructions for equipment maintenance. [...] This differentiation in some cases was minor and in some others was more radical. [...] (For example) We reduced the frequency of inspections to equipment that didn't need it. [...] During the execution of the instructions we eliminated some unnecessary steps, while we added our own steps. [...] Another example is that we replaced recommended inspection techniques with other more appropriate (techniques) for our equipment. If we aren't in a position to decide the most applicable method for our refinery then none can do so. [...] Personnel perceived it as a challenge. They said: "We have something good, but let's improve it!". I think that only after all these changes preventive maintenance started to have a meaning for us."

An ED engineer noted:

> "Obviously preventive maintenance reduces uncertainty. Instead of waiting for something to happen you trace it in advance and then have the luxury to think about what to do. It also reduces damages and other consequences. You know that there are specific motors, which in case of failure can cause the shutdown of the whole refinery. Now, we don't have to wait until they fail!"

In addition, an ED engineer noted that nowadays the ED personnel perform maintenance tasks without even looking at the standards or the manufacturer's instructions, highlighting the tacitness of the work execution routines:

> "No, all this knowledge isn't recorded anywhere in the form of formal maintenance strategies and preventive maintenance routines. [...] Of course, we keep studies, blueprints and other documents, for reference which can help you make estimates, but we're mainly based on the competence of our personnel"

Moreover, and besides the example of the ED, an ID engineer highlighted the existence of a departmental policy for the acquisition of preventive maintenance skills:

> "Our personnel are well trained in the use of various testing devices for instruments. [...] We even know how to use devices that are used by suppliers and contractors and we don't have them in here."

The utilization of these skills is justified by the benefits of preventive maintenance. Thus, the ID head explained using the example of instruments calibration that his personnel embraced preventive maintenance approaches, since they enhance the departmental ability to act (Stehr 1992):

> "We're in a position to make quick decisions. [...] For example, we know that if an instrument that was calibrated recently shows a strange indication, it probably needs to be replaced. Or if we attempt to calibrate the instrument and we see that it's not in a good condition we replace it."

The transition into a preventive maintenance approach for both the ED and the ID was also supported by the existence of a number of mechanisms (Schein 1985) that facilitated the shaping of a preventive maintenance culture. Hence, for example, the attachment of national and international standards along with performance indicators reports to the JPs act as a measurement and control mechanism (Schein 1985) during the job execution. An electrical engineer indicated the contribution of supervisors in the shaping of a preventive maintenance culture with the use of such standards:

> "I don't think that if our supervisors weren't well educated they could perform their job. [...] They wouldn't be in position to coordinate the crews and control their work. [...] It's very important that they can take the standard and guide the technicians. In other departments supervisors can't even speak English. How would you expect them to use (foreign) standards?"

The same engineer explained how departmental supervisors use these standards in job execution:

> "The standard is a safety bar. There are straightforward guidelines for the execution of the work. Based on this, supervisors judge the quality of the work of technicians and we (engineers) can verify at any time if their work reaches the desired level. [...] We don't check everything. Supervisors do. We selectively pick important jobs to inspect."

Moreover, another culture embedding mechanism has to do with the emphasis that is put on the teaching and coaching of the ID and the ED personnel in relation to the acquisition of preventive maintenance techniques. Even the example of exercises that simulate failures at the ED can act as a role modelling mechanism (Schein 1985) that demonstrates the adoption of a preventive approach to crisis situations. The head of the ED indicated that the embedding of a preventive maintenance philosophy is facilitated by the fact that it gives a permanent answer to the question of the utilization of idle personnel, since it involves more personnel than reactive maintenance.

However, other conditions are not so favourable for the creation of a preventive maintenance culture. Hence, the existence of outdated written procedures coupled with the lack of formal statements about departmental and divisional philosophies do not help the articulation and reinforcement of a preventive maintenance culture. For example an ID engineer noted:

> "The existing (official) departmental procedures are at least ten years old and they definitely have nothing to do with a preventive maintenance philosophy. Besides we don't use them. [...] We would never give them to a new employee to read about the operation of the department!"

Additionally, the existence of a non-standardised way for promotions and for rewarding personnel within the MD do not facilitate the promotion of a desired departmental culture.

In contrast to the cases of the ID and the ED, the RED provides a particular example in which the development of some preventive maintenance routines is not followed by the concurrent development of a preventive maintenance culture. The department head indicated the partial development of preventive maintenance routines, which started in early 1980s:

> "We don't use autonomous teams officially, since preventive maintenance is limited mainly to pumps and compressors. [...] I believe that it's feasible to develop a fully-fledged preventive

maintenance programme for many equipment categories provided that we'll be given the necessary resources."

A RED engineer explained that the department has sufficient preventive maintenance skills:

"We've all the necessary skills for the preventive maintenance of pumps and compressors within the MD."

Hence, despite the fact that the RED uses equipment condition monitoring techniques for some types of equipment, it has not integrated them within a holistic preventive maintenance scheme. The same engineer highlighted that the department has neglected the acquisition of preventive maintenance skills for other equipment groups:

"We haven't attempted to bring any other (preventive maintenance) techniques for at least ten years."

The RED engineer in the same interview also gave an example of the multi-dimensional and multi-actor departmental maintenance routines:

"For example, with vibration analysis we can estimate when a pump is bound to fail. [...] The technique is applied by a specialized crew. [...] (However) The result (interpretation) of the measurement is always the object of discussion between the operator, the supervisor and some technicians. [...] The course of action is not standardised. Depending on the situation they can apply a number of solutions. [...] For example, instead of changing the shaft of the pump, they may decide to try a different lubricant[60]. [...] Then, once the supervisor with the crew and the operator agree on some solution, the operator makes the pump available for the repair and we proceed. [...] The actual repair involves at least a team of three people. Only the lubrication crew consists of two people. Other repairs are far more complex."

Furthermore, and as the engineer noted, the departmental routines are largely tacit:

"Decisions are usually made on the spot. Supervisors don't usually open manuals in order to choose a repair method. Of course, neither do technicians open manuals when they repair the equipment."

However, the indications for the development of preventive maintenance routines are not followed by similar indications for the development of a preventive maintenance culture within the RED, since a number of mechanisms (Schein 1985) appear rather weak. For example, the relative absence of explicit measures and controls causes difficulties during the JP execution. A supervisor explained:

"We control the performance of the crews, but there aren't written guidelines anywhere. We decide according to each case."

The same supervisor pointed out the lack of direction:

[60] Note: Suitable lubrication may extend the working life of the pump

"In fact discussions about a preventive maintenance philosophy seem strange to us. [...] I don't think that middle management who haven't done anything for the organization of our work will change to a "preventive maintenance philosophy", which requires a maximum degree of organization!"

On the other hand, the example of the SED is another totally different case, since it demonstrates both the existence of espoused reactive maintenance routines and culture. A supervisor highlighted the total absence of preventive maintenance using an example of the simplest equipment maintained by his department, the strainers:

"For years we've been discussing the regular (proactive) cleaning of strainers, but nothing's been done. Everybody remembers it just before it blocks completely and then we try to avoid the consequences!"

However, a departmental engineer gave another perspective:

"Technicians consider the cleaning of strainers as a task that depreciates their value. [...] Just like technicians at the RED avoid the lubrication of pumps."

Hence, departmental personnel noted that their routines are reactive, while a supervisor showed the existence of historical links (Cohen and Bacdayan 1994):

"We've been working with the same system since I joined the company."

A SED engineer described some aspects of these long-established reactive maintenance routines and the department's ability to act (Stehr 1992):

"We receive WRs from paniced operators. They usually mumble about disruption to their production schedule. They complain that we should inspect pipes more often, when they know that this is a responsibility of the Inspections Department. Everybody wants a quick repair and everybody thinks that it's the simplest thing in the world, because we deal with the piping network. They usually have a ready excuse: "It's only a leakage, you have to fix it immediately". [...] What can you do then? First of all you have to get all these people off your back in order to be able to work. We use by-passes and other temporary solutions. We buy time for the assembly of the crew and the materials. [...] You can't imagine what we have to go through in order to find even one available welder."

A supervisor added:

"We feel like we are chased and this makes our work very unpleasant. [...] The most difficult thing for us is the rescheduling of technicians."

A SED engineer agreed with the supervisor:

"The organization of each repair is the most difficult phase. Once we find the personnel then the work is streamlined."

In addition, conditions within the SED do not favour a preventive maintenance culture. For example, the JP does not contain measures and controls, such as standards, for the assessment of the technical work. A supervisor noted:

> "We can't control and inspect all of the (technical) work. We inspect the most important WOs."

Furthermore, the unofficial system of rewards promotes the continuation of reactive maintenance. An engineer noted:

> "This (reactive maintenance) system is very convenient for those who want to work overtime. [...] When top management and the OD puts pressure for quick restoration of the repair then they don't mind authorizing people to work overtime."

Furthermore, the existing organization of Petrochem and the procedures for the initiation of maintenance work contribute to the maintenance of a reactive culture. Hence, the Inspection Department deprives the SED from the most important preventive inspection method for static equipment, thickness measurements. The SED head said:

> "Preventive maintenance techniques and methodologies for our equipment are well-known, but their application belongs to the Inspections Department, which also has the archives with the inspection measurements."

Then, a SED engineer noted:

> "In fact thickness measurements are the most important responsibility of the Inspections Department. Normally their activities are an extension of ours, but traditionally they've been independent. [...] They organize their measurements programme without any help from the MD. We only receive WOs when their personnel think that we have to repair something. [...] There aren't any particular problems in our relationships, we just don't have very close collaboration."

Finally, and besides the examples of the departments of the MD that execute the repairs, the PD provides a special example of reactive approach to the maintenance workload. The department head noted:

> "Given the circumstances we aren't able to foresee and control the developments within the MD, we've no other option but to follow the developments."

In addition, an engineer said:

> "Of course we (PD) realize the potential benefits from the adoption of a preventive maintenance strategy, but the road for the adoption of a unified preventive culture across the MD requires both much effort and management commitment."

In fact, the PD steps in the job execution routine only after the completion of the maintenance work in order to record the final outcome. However, both the description of the performed maintenance works and the provision of feedback about the quality of the work face problems. For example, a RED engineer highlighted that knowledge "escapes", since detailed descriptions about the execution of the job are not kept due to "the difficulty of the technicians and the supervisors who provide the information to explain what they actually did, despite the fact that they've done it successfully" and because the PD, which is responsible for this recording, "doesn't understand such information and so planners aren't interested in it". The same engineer added:

> "The details of the executed work and know-how remain within the team (engineer, supervisor and technicians), which dealt with the problem."

In addition, the ED head provided another perspective regarding the degeneration of this process:

> "Well, most of electrical maintenance works are standardised and departmental engineers and technicians very often use national standards and manufacturer's instructions, so they rarely keep any other documents or additional information about the executed work."

The PD head added about the capturing of information on the WO after the completion of a maintenance task:

> "The information for the WO is usually provided by the supervisor, and scarcely by the engineer. While they're responsible for the work quality, they never check the (WO) document. [...] Even though, the technician who dealt with the problem can give the most accurate information (about the executed work), we rarely talk to him. We also usually manage to record only some of the people who dealt with the execution of the WO, and not how many hours they spent on the problem. Not even the supervisors can tell for sure. [...] Spare parts are also much more difficult to record than the number of participants and so we don't keep exact quantities."

Furthermore, quality control at the MD is usually performed by the supervisors, who approve the executed work before they announce its completion to other departments, such as the PD. Supervisors approve all maintenance works executed by refinery technicians and external contractors. During discussions a RED supervisor mentioned:

> "The responsibility for the technical and operational completeness of any kind of job is huge, even in cases in which engineers control us at a later stage."

Discussions also revealed that supervisors provide feedback to technicians sporadically, whilst middle management is also not very concerned about feedback loops. A supervisor highlighted the existence of a "just get it done" mentality, which was also reflected during the Cultural and Satisfaction Survey:

"Once the work's completed, nobody cares about it any more."

This also explains why quality control is not combined with any established feedback of information. Discussions during the training seminars revealed that the Division is unfamiliar with the concepts of quality control through the development of a holistic philosophy such as Total Productive Maintenance (TPM), the equivalent of Total Quality Management in maintenance, which could be used in order to enable employees to improve maintenance repairs by articulating tacit knowledge gained at the workshop. A maintenance supervisor said:

> "TPM seems to us something from outer-space because of its requirements, which certainly don't fit local conditions. [...] TPM will probably fail because of the inability of the PD to use such a tool and the unwillingness of the OD to participate in any improvement initiative from the MD."

In addition, another supervisor connected the possible failure in the use of TPM with lack of a clear vision since top management does not provide "a realistic maintenance strategy".

6.6 Conclusion

Since this research assumes that in order to understand organizational knowledge and the process of its creation there is value in understanding work and its context, chapter six narrated episodes of the maintenance service work at the MD through a range of themes. These themes describe the natural maintenance workflow at the refinery. Thus, the first theme dealt with the process of maintenance skills acquisition, and with the process of information transfer and collection, both from within and outside the MD. Hence, the theme described opportunities for the acquisition and sharing of experiences and the development of a worldview shaped from various, and often contradictory, perspectives. It also brought forward some face-to-face deliberate and spontaneous interactions that influence this socialization process. The second theme explained how maintenance personnel use acquired skills and know-how to build hypotheses about equipment faults and to formulate preventive and reactive maintenance repair concepts. Through the established procedure for requesting and authorizing maintenance work, the theme also pointed out patterns of action and interaction of the participants in this process. The third theme described the planning and scheduling function of maintenance works through the story of the maintenance Job Plan and presented a number of associated issues. The last theme dealt with the execution of the maintenance repair and uncovered this multi-actor routine by describing its two fundamentally different branches, the preventive maintenance and the reactive maintenance branch and their associated subcultures. Furthermore, this theme pointed out the importance of experimentation and simulation within this job execution routine.

Having described the case organization and the nature of its activities (Chapter 4), the conditions under which these activities are performed (Chapter 5), and the actual flow of maintenance work (Chapter 6), the next chapter attempts to make sense (Weick 1988; 1993; 1995) how new maintenance knowledge is created through these everyday service activities.

7

Making Sense of the Maintenance Knowledge Creation Process

7.1 Introduction

The major findings from the Petrochem case study highlight the ways in which this research has focused on maintenance service work. Existing literature in the fields of knowledge management and organizational studies has examined in the past aspects of knowledge creation, such as for example, the importance of knowledge assets. Nevertheless this literature has tended not to inquire into knowledge creation as a process and therefore little attention has as yet been given to the interrelationships between the process and its context and its content. The analysis of maintenance service work in this chapter through a knowledge creation perspective endeavours to cover this gap.

The analysis of the data and empirical findings thus far presented is based upon the theoretical framework, which was introduced in Chapter Two. This framework combines Nonaka's Unified Model of Dynamic Knowledge Creation with taxonomies and frameworks from the literature, achieving a theoretical kind of triangulation (Denzin 1978), which consists an important methodological contribution of the research. These supportive taxonomies and frameworks delineate aspects of the SECI process by identifying episodes of the knowledge creation process (Nonaka et al. 1994) and the stages of socialization (Feldman 1976; 1981). They also allow making sense of the social and the organizational context of the process by bringing forward important individual and group roles for knowledge creation (Von Krogh et al. 1997).

Moreover, these taxonomies and frameworks delineate aspects of the process content, and in particular of the intangible knowledge assets, such as trust (Newell et al. 2002), care (Von Krogh 1998) and improvisation (Moorman and Miner 1998).

The present analysis of the maintenance works, which points out interrelationships within the knowledge creation process, its context and its associated knowledge assets, contributes not only explanations, rich insights and specific conclusions about the knowledge creation process and its management in the refinery, but also insights and ideas for conceptual developments with respect to the theoretical frameworks being used.

Interpretation commences with a group of themes that focus on the conditions that vitalize, energize and give quality to the knowledge creation process and to its context, and bind participants in it. These are the conditions of care, trust, commitment, autonomy, creative chaos, information redundancy and requisite variety. Moreover, this group of themes also analyses the existing knowledge vision within the case organization.

Having analysed the conditions that influence knowledge creation, the heart of this chapter unfolds in the subsequent four themes, which correspond to the four stages of the SECI process, as these are identified in the natural flow of maintenance works. Hence, the first theme pertains to the socialization stage of knowledge creation within the case organization - seen as a process of tacit knowledge transfer and accumulation and as a process of internal and external information collection. The theme explains the skill acquisition process and the situations that allow personnel to gather contextual and other information. The second theme analyzes the externalization stage of knowledge creation as a process in which maintenance personnel explicate their tacit knowledge, when they make use of their maintenance skills during the identification of faults for equipment repairs. The third theme, initiated by the planning and scheduling function of the maintenance organization, analyses the combination stage of knowledge creation as a process that involves the acquisition, integration and processing of explicit knowledge for the synthesis and dissemination of complex explicit knowledge sets. The fourth theme views the execution of maintenance works as the final stage of the knowledge creation process in which personnel create and acquire new knowledge not only on technical maintenance issues, but also on the management and organization of maintenance works – on the organizational capacity to act in other words.

Concurrently with the analysis of the knowledge conversion stages of the knowledge creation process, emphasis is given to the influence of the process context and the involved knowledge assets. The analysis of knowledge creation as a process not only indicates its context-specific nature, but also points out the coexistence of many and often substantially different modes of this process, which result either in reactive or in proactive maintenance. Their differences often depend on how and who participates in the process and reflect that the process context acts as the platform not only for knowledge creation, but also for knowledge sharing, integration, and utilization.

The chapter concludes with a brief summary.

7.2 An analysis of the conditions that energize the context for knowledge creation

7.2.1 An analysis of the conditions of care, trust and commitment

Trust, care and commitment within the MD stimulate and regulate peoples' interactions and intentions to act in various and, often, contradictory ways. The research indicated that not only are they created and determined, to a great extent, during the socialization stage of knowledge creation, but also that the influence of these experiential knowledge assets remains strong throughout the whole process.

Collected data indicate that trust within the case organization is created through opportunities that are given to an employee mainly during the first period of his employment by participating in long-lasting job rotation and mentoring schemes. This participation initially creates a process-based type of trust, which involves socialization interactions, and is based on personal friendships. It can therefore be characterised as a companion type of trust (Newell et al. 2002).

Not only engineers, but also low-level employees are involved in this trust building process during the commencement of their employment. Hence, during the unofficial mentoring schemes (Ivancevich and Matteson 1999), engineers create personal friendships and nurture high care relationships (Von Krogh 1998), which form the basis for companion trust that requires reliance on work comrades. Then, along with the building of friendships, employees acquire context specific knowledge and skills through interactions that occur during the accommodation and role management stages of socialization (Feldman 1976; 1981).

However, the building of companion trust is only a stepping-stone, since it facilitates the accumulation of knowledge for the building of another type of trust that develops more swiftly in the action of maintenance works. Hence, sooner or later newcomers, either engineers or technicians, have to demonstrate their maintenance management and technical skills to their colleagues. According whether the skills demonstrated are seen to be competent, a competence type of trust (Newell et al. 2002) is created (or not). The successful application of managerial and technical skills to real world situations is perceived as an indication that the individual is competent (Dreyfus and Dreyfus 1986) and his colleagues can rely on his expertise. Once demonstrated the employee concerned is permitted to participate more actively in the knowledge creation process.

In the MD judgements on competence are expressed by supervisors. In doing so they regulate the process of building competence trust for all employee levels and for external contractors and suppliers. Their role is enabled due to the fact that they are considered as role models (Schein 1985) by low-level employees and as experts by engineers. This also explains why technicians seek to gain their companion and competence trust (Newell et al. 2002).

Supervisors use competence trust as an important resource allocation criterion (Schein 1985) for employee participation in various maintenance microcommunities, contributing decisively to the involvement of individuals in the Ba of the knowledge creation process. In the absence of a formal reward and payment system that could possibly fortify the maintenance job initiation and execution routines, lower management's trusted technicians are in general the committed group that is given the opportunity to accumulate additional skills and know-how in contrast to other less trusted employees, who do not have the privilege to practice their skills so often.

However, the trust building process does not create homogenised companion and competence trust throughout the company, since the existence of functional and hierarchical boundaries contribute to the creation of high and low trust interactions. The research indicated that when trust runs high both personal and professional interactions are intense, such as the interactions between middle and lower management of the ED.

In general, within each department the existence of companion trust (Newell et al. 2002) is reflected in harmonious personal relations within groups, the lack of significant cooperation problems (Mayer at al. 1995; McAllister 1995; Jones and George 1998), and with the provision of support in the employees' everyday life problems, such as in the case of supervisors that allow technicians to leave early in order to take care of family issues.

Without neglecting that sometimes a relative lack of trust may also exist between hierarchical levels with frequent interactions, such as between engineers and lower management (since the performance of the role of the knowledge catalyst by the latter group empowers them significantly) the greater the distance between two hierarchical levels, the greater the possibility that limited competence trust will be formed between them. Thus, for example, low-level personnel do not always trust top management's managerial skills, especially in issues concerning the firm's future. This is of particular importance for the knowledge creation process, due to its impact on the process's direction and coordination. Middle management, in attempting to protect the rather fragile trust relationships (Ring and Van de Ven 1994) with their colleagues from low levels and in demonstrating that they do not abuse power (Shapiro 1987; Whitener et al. 1998), often pin the responsibility for the introduction of ambitious goals on the OD. Nevertheless, such behaviour contributes to the creation and maintenance of mistrust relationships with this division. This is reflected in the limited coexistence of participants of the MD and the OD in fault identification and in planning and scheduling discussions - in the dialoguing and systemizing Ba (Nonaka and Konno 1998).

Furthermore, and when it comes to interdepartmental trust, the existence of boundaries become apparent from the isolation of large groups, such as the PD. Such phenomena are indicative of the lack of competence trust and the existence of mistrust. Hence, mistrust towards the maintenance planning and scheduling competencies of the PD limits its participation in Ba, in particular in participating in various maintenance activities, and also prevents its personnel from developing common understanding with other departments regarding maintenance activities. This reflects the absence of the role of the merchant of foresight, who could assist the bridging of the gap (Edmondson and Moingeon 1999). Hence, lower management, who enjoy the competence trust and the strong confidence (Mayer at al. 1995) of other departments, are given the opportunity to act as connectors of knowledge initiatives for maintenance planning.

Nevertheless, the research also indicated the rather complex interrelation of trust with other experiential knowledge assets. Hence, the example of the WD demonstrated that despite the existence of a moderate degree of distrust of departmental abilities, high care relationships, which are reflected in lenient judgement, ensure the WD's interactions with other maintenance executing departments.

Hence, this plurality of trust and distrust relationships within the MD is often coupled and co-exists with both low- and high-care relationships (Von Krogh 1998). The shaping of high-care relationships is promoted by the long-lasting employment of personnel and low employee turnover. This environment during the past ten years assisted the development of common personal histories (Von Krogh 1998) and the creation of a "family feeling", despite opposing conditions, such as the rapid expansion of the company and its quite recent privatization. Besides the sharing of a common history, the compatibility of maintenance work scopes and business layers (Nonaka 1994) also provide a common ground for such high care relationships, such as between the ID and the ED. The common work scope in conjunction with the small size of the Greek market and the limited competition, contribute to the building of high care and companion trust relationships (Newell et al. 2002) even with external groups, such as contractors and equipment manufacturers (Badaracco 1991; Ring and Van de Ven 1994).

The research has shown that high care relationships are expressed with the demonstration of mutual companion trust, empathy, the provision of help to departmental colleagues, and lenient judgement (Von Krogh 1998) that facilitates the open expression of opinions and actions. The communication of companionship as a corporate value (Von Krogh 1998) by top management, which acts as a primary culture embedding mechanism (Schein 1985) is also a demonstration of high care. As examples indicated, with the existence of this experiential knowledge asset knowledge creation becomes, both interdepartmentally and interorganizationally, what Von Krogh (1998) calls a "knowledge indwelling process".

Nevertheless, at the other extreme, examples of low care relationships were also frequent and indicated that individuals capture knowledge (Zand 1972; Von Krogh 1998) and create power kingdoms, when other participants have not developed a certain level of understanding and cannot interpret information provided, or when there is lack of competence trust. Such behaviour contributes to the creation of knowledge differentials and it is an additional reason why large groups, such as the PD, do not participate in the knowledge creation process as equal members. In such cases criticisms are common, while often either there is no interest or no attempt to share knowledge or provide feedback to others.

On a social level, and especially at the higher management levels, where conditions provide opportunities for personal development, relationships across departmental boundaries are often characterized by competition, power struggles and criticism, despite the evident signs of companionship. In such low care instances, knowledge creation degenerates into knowledge transactions (Von Krogh 1998), often influencing trust at the lower levels.

Besides trust and care relationships, a practical contribution of the research concerns the explanation that interactions during everyday maintenance activities are also influenced by the existence of committed or less committed individuals. The investigation demonstrated that committed middle managers often act as knowledge catalysts triggering many knowledge-creating initiatives related to technological innovation (Price 1997; Naito 2001), such as in the case of the substation network. Moreover, lower management's commitment created knowledge in the form of substantial improvements in more practical issues, as the example of the supervisor, who upgraded the piping network, indicated.

Commitment (Price 1997) and motivation for the sharing and creation of knowledge appears to depend mainly on individual initiatives and goodwill. Such commitment is generated by a variety of factors (Blau et al. 1993; Kalleberg et al. 1996). Thus, in particular, committed middle management are often characterised by selfless behaviour and identification with their job, seeking the satisfaction of accomplishment, rather than career development and financial rewards (Blau et al. 1993; May et al. 2002). Other important commitment factors for all employee levels include the identification of personal values with expressed organizational values (Kalleberg et al. 1996), the national importance and the social responsibility of the refinery, and job security (Blau et al. 1993).

In contrast, commitment and motivation of less self-committed, "nine-to-five" employees is connected to opportunities to increase income (Blau et al. 1993) through overtime. Additionally, the lack of an official reward system (Blau et al. 1993) and the existence of legislative barriers for personal development for some hierarchical levels moderate the commitment of some other employees. Along with this loose commitment is the impediment of the promotion of high care relationships (Von Krogh 1998) and knowledge sharing with fellow colleagues. Furthermore, commitment is influenced by the fuzziness of the existing vision and corporate purpose, which, coupled with a rather ineffective vertical and horizontal communication system, fail to coordinate personnel's intentions and to promote the knowledge sharing (Nonaka 1994; Price 1997).

However, the relative gap in commitment amongst the lower level employees is covered by lower management, which by acting as merchants of foresight, foster commitment.

7.2.2 An analysis of the condition of autonomy

Within the MD there are frequent opportunities for autonomous action and interaction, despite restrictions and barriers that have prevented the organization from creating both cross-functional autonomous teams and a flatter structure. These restrictions are set by the rigid legislative framework regarding professional qualifications and rights, which prevent the personal development of employees at certain levels. The same framework also bars autonomous empowered decision-making and action (Nishiguchi and Beaudet 2000) at lower levers. Furthermore, legislation imposes a centralized financial control system (Daft 1995; Mainz et al. 1990; Owens 1991), putting an additional burden on the autonomous action of maintenance departments.

Nevertheless, the opportunities for autonomous action and interaction allow employees of all levels to frame maintenance problems, very often with innovative thinking, before they proceed to their resolution. Such autonomy is very important for the knowledge creation process, since it facilitates the creation of new knowledge by enabling the innovative framing of problems. Hence, employees, such as middle management, who are not affected by the above-mentioned restrictions, enjoy an enhanced degree of autonomy that frequently motivates them to create new know-how concerning the organization and management of maintenance activities (Nonaka et al 2001). In addition, their autonomy increases their chances of accessing and utilizing existing and new knowledge (Grant 1996a; 1996b), since, for example, engineers are free to request participation in seminars and educational trips. Consequently, middle management often act autonomously both as merchants of foresight, promoting innovative ideas, and as catalysts for knowledge creation initiatives, facilitating the application of these ideas.

Furthermore, top, middle and lower management by acting as merchants of foresight encourage formal and informal autonomous experimentation (Nonaka 1994, Cohen et al. 1972) of all employees. This kind of autonomy motivates individuals, provides opportunities for the accessing and utilization of knowledge (Grant 1996a; 1996b), and promotes the investigation of attractive ideas, which in the industrial context of the case organization are often associated with technological innovation. Thus, such autonomous individuals often act as knowledge catalysts who facilitate the introduction of an experimentation culture and enable objectives to be set that lead to the creation of beneficial for the organization knowledge, often spanning departmental boundaries.

At lower levels autonomy finds a way out through the operation, under the leadership of lower management, of unrecognised (Wegner et al. 2002), quasi-autonomous and functional teams. At a decision-making level (Mainz et al. 1990; Owens 1991; Daft 1995), these teams have the authority to set their own objectives, and despite the fact that they are not officially empowered to take action, they often do so. A basic reason that contributed to the institutionalization of this status quo has to do with lower management's power of knowledge (Badaracco 1991; Introna 1997; Newell et al. 2002; Sinclair 1992), which allows them to act as field counsellors and achieve a good use of existing knowledge (Grant 1996a; 1996b) by dealing with "the cascades of information" (Brown and Duguid 2000). Moreover, supervisors, by acting as knowledge catalysts, resolve problems caused by management's decisions, such as the sudden changes in the work activities.

Maintenance teams are not entirely self-organized in a similar way to autopoetic systems (Von Krogh 1995, Maturana and Varela 1980; Nonaka 1994; Varela 1984), since their Ba is deliberately created by supervisors, who control the integration mechanism (Newell et al. 2002) of team members' selection, ensuring a desired mix of skills and conformity (Janis 1982), and handling issues of power (Badaracco 1991; Sinclair 1992; Introna 1997; Newell et al. 2002). Furthermore, lower management, by acting as knowledge connectors, encourage teamwork, promote cooperation between various teams and groups, connect Ba into a greater, coherent Basho (Nonaka and Konno 1998) through organic interactions, and regulate access to information channels. Thus, autonomous supervisors achieve important reductions in time (Ivancevich and Matteson 1999) during maintenance work, since they cater for the unrestricted access to valuable information by team members. This is reflected in the case of the autonomous action of "warehouse technicians".

Nevertheless, not all autonomous teams created by supervisors within the MD are the same, since they vary significantly not only in their size, but also in the supervisors' educational background. Hence, a practical contribution of the research concerns the explanation that in departments with better educated supervisors, such as in the ED and the ID, and in contrast to departments that adopt a reactive approach to maintenance, lower management may act as merchants of foresight, since their educational background allows the interpretation and transmission of the knowledge vision, such as in the case of the substation network. Furthermore, in the same departments the relatively small autonomous teams support quality face-to-face interactions that promote internal knowledge transfer in a nurturing environment.

7.2.3 An analysis of the condition of creative chaos

The constant and artificial stimulation of the interactions between the MD and the OD by the autocratic "navy culture" of the OD, which was formed under the influence of external social factors, evokes a sense of crisis among the members of the maintenance organization. Such a sense of crisis leads to the solution of problems by causing breakdowns of routines, habits and cognitive frameworks (Weick 1988; 1993), since they require urgent response from the maintenance personnel. Top management's consensus and attitude maintains the operator's culture and limits the potential for change. This artificial stimulation is long-established and prevents the organization from falling into complete disorder, since it is also well tested (Nonaka et al. 2001).

Nevertheless, the existing reality differs significantly from the ideal of creative chaos (Nonaka 1988a), since the "just get it done" environment limits the time required for self-reflection, and employees are neither in a position to define the problem, nor to imagine easily their potential role in its solution.

Moreover, "conflicts" created by the navy culture are not channelled into the creation and energizing of dialoguing Ba, because machine operators provide few explanations (Leonard 1998) reducing opportunities for fundamental thinking and perspectives (Weick 1988; 1993). The lack of common objectives also contributes to the lack of collective efforts between the two divisions. On the contrary, the excessive use of the navy culture for evoking crisis reproduces interaction patterns of mutual mistrust between the MD and the OD.

Hence, exchange between these two divisions is merely an information transaction, and the energy and motivation of these interactions are extrinsic (Senge 1990b). Thus, the objectives of the case organization are mainly set by others, meaning the OD, while the MD, demonstrating diffidence, avoids the open setting and pursuit of ambitious targets. This also becomes evident not only in the MD's difficulty to prioritize maintenance works, but also in the existence of an environment that avoids constructive criticism, since such feedback is often coupled with low care relationships.

Management also fail to play the knowledge catalyst role, since they do not use tools and methodologies that could allow personnel to read the current situation and introduce creative chaos intrinsically (Senge 1990b) by setting objectives, while they also avoid openly asking questions. Instead management allow the uncoordinated deviation from established practices due to a lack of concrete problem framing and solving methods, since, for example, they do not use any shared map of cooperation neither for the management of conversations during the faultfinding process, nor for the capturing of explicit knowledge. This contributes simultaneously to the uncontrolled creation of a sense of crisis through uncertainty and relative instability.

Middle and lower management make an opportunistic exploitation of such crisis situations, which besides the navy culture, can also be evoked by many other factors, such as an unexpected increase at the workload, employment procedures and unequal personnel distribution, for the imposition of mainly time-related targets (Nonaka 1994; Nonaka et al. 2001a). Less frequently management introduce clear policies that achieve the external transfer of skills and know-how (Teece 2001) and the sharing of knowledge (Swart and Kinnie 2003). However, this feeling of urgency is often coupled with implicit threats and financial rewards that limit opportunities for fundamental reflection and for the provision of perspectives deeper than a superficial level (Nonaka 1994, Nonaka et al. 2001; Weick 1988; 1993). In such instances, participants are committed due to fear of possible consequences and this could force them to settle for less, since risk mitigation becomes a primary criterion for justifying their beliefs.

7.2.4 An analysis of the condition of information redundancy

In the absence of a fully developed job description system and a standardised training programme, the intentional sharing and overlapping of redundant information and knowledge (Nonaka et al. 2001) about business activities and assigned responsibilities within the case organization has been achieved mainly through two complementary, non-standardised, interdepartmental and intradepartmental, kinds of job rotation. Hence, information redundancy occurs primarily through the same process, which contributes to the building of trust and intimacy, and the development of a common history between the employee and his colleagues. Other ways for the realization of information redundancy appear rather weakened, since, for example, the use of official documents, such as internal regulations, is only supportive.

On the one hand, job rotation allows individuals to understand their role within the organization (Nonaka et al. 2001a) as "it prepares them to believe" (Dretske 1981) various viewpoints and objectives, while it opens a dialogue between inside and outside perspectives (Wegner et al. 2002), since, for example, socialization interactions with employees from various departments facilitate the sharing of tacit knowledge. Concurrent with the trust building process, job rotation establishes friendships and communication channels (Introna 1997; Rogers 1995). These channels provide the employee with advice and information from different perspectives and resolve issues of information and knowledge location and storage, since job rotation creates a common ground for conversations (Nonaka 1990).

Nevertheless, redundant information goes further than the creation of dialoguing or other types of Ba. Thus, redundant information acquired through job rotation also controls and directs employee thinking and actions (Nonaka 1994), since personnel can sense what others are trying to articulate (Nonaka et al. 2001) and therefore coordinate themselves better with the departmental objectives and activities.

In addition to interdepartmental job rotation, intradepartmental job rotation is responsible for the organized overlapping of maintenance skills (Von Krogh and Kameny 2002) through interactions that include demonstrations by senior colleagues and mentoring. Hence, personnel not only develop an understanding about the departmental activities, but also realize the overall objective of the maintenance work, while they create tacit maps about stocks of existing knowledge assets that will be used in their everyday working life.

However, the redundancy of information through job rotation also has some weaknesses. It increases cost (Dretske 1981; Nonaka 1990), generates unequally skilled and informed personnel, and encourages subjective interpretations whether an employee is considered competent and trusted. Furthermore, the establishment of informal communications channels fortifies the informal maintenance organization. Nevertheless, in cases of limited job rotation, such as between the OD and the MD these communication channels appear somewhat weakened.

Additionally, in the absence of standard criteria for job rotation, lower management often act as knowledge catalysts (Von Krogh et al. 1997), who know where to find the knowledge and the personnel that will enable the exploitation of this knowledge. Therefore, by regulating the job rotation process, they control the rather opportunistic transfer of employee skills (Von Krogh and Kameny 2002) and the provision of redundant information.

The research indicated also that protracted job rotation minimizes the possibility of an information overload. However, when job rotation comes to an end the opportunities for the acquisition of redundant information is more limited, with the exception of middle management, for whom job rotation remains an option throughout their career.

Besides job rotation, which is the primary mechanism for redundant information within the case organization, the research also pointed out the complementary role of seminars and conferences, which again concern middle managers, and the limited contribution of simulation exercises that enable employees understand some aspects of their position within the refinery.

Finally, the limited, if non-existent utilization of ICT (Ciborra 1996a; Grudin 1994; Kock and McQueen 1995; 1998) indicates that flows of redundant information are maintained mainly through the communication channels established during job rotation and other socialization interactions with fellow colleagues, such as the case with the warehouse technicians.

7.2.5 An analysis of the condition of requisite variety

Evidence from the case organization indicates the dual face of the condition of requisite variety, since on the one hand there are numerous opportunities for the different, flexible, and quick combination of information that allows for an effective response to environmental fluctuations, while on the other the "equal access to information throughout the organization" (Nonaka et al. 2001) seems utopian.

A minimum of requisite variety is achieved through the unofficial job rotation scheme (Lessem 1998; Lessem and Palsule 1999; Nonaka 1994) that promotes a level of organizational integration and cohesion by developing a common understanding (Nonaka and Takeuchi 1995; Rogers 1995), and establishes communication channels for the acquisition and sharing of interdisciplinary knowledge (Introna 1997; Rogers 1995; Postrel 2002).

Nevertheless, a practical contribution of the research is the demonstration that technological innovation appears to be one of the most decisive factors for the further development of requisite variety. Maintenance personnel involve themselves in such innovations in two distinctive cases, which differ in scale. First, the participation of personnel in non-maintenance activities ensures their participation in large technological projects for the construction of new units. Top management, in the role of merchants of foresight (Von Krogh et al. 1997), encourage this activity that provides requisite variety enhancing opportunities, since employees learn to deal with environmental complexity and to adapt to environmental changes (Nonaka et al. 2001). In doing so, management promote the realization of multiple financial, technical and human resource utilization benefits.

Non-maintenance activities bring personnel in contact with technological discontinuities (Tushman and Anderson 1986) triggering the building of organizational combinative capabilities (Kogut and Zander 1992) and the fortification of a culture (Schein 1985) that embraces new and diverse developments (Nonaka et al. 2001a) and fosters creativity (Vicari and Triolo 2000). These requisite variety opportunities also couple on the spot training with the motivation from the salaries' subsidies and the sense of crisis caused by increases in workload.

Within the MD the ED was the only department, which realizing the value of experiences from non-maintenance activities, such as the construction and the operation of new electrical units, decided to institutionalize this window for acquiring new knowledge and skills ensuring the direct inflow of information by adapting its organizational structure – in other words its business layer (Nonaka 1994). Thus, the establishment of the New Installations Crew allows employees to grasp directly external perspectives, learn about new technologies and discover differences with older technologies.

However, opportunities for participating in the Ba of non-maintenance activities are not equally distributed, preventing the realization of organization-wide requisite variety. The existence of competence trust is a prerequisite for the participation of an employee in new construction projects. Thus, Ba loses its "here and now" (Nonaka and Konno 1998) quality, since participation in it, at least for this particular this type of Ba, appears fairly stable and is strongly dependent on the existence of competence trust. Consequently, it takes considerable time for someone to become a full participant in this type of Ba and this is an indication that the referring Ba has some similarity with the communities of practice (Lave and Wegner 1991).

Besides technological innovations in the form of large-scale constructions, another important opportunity for the promotion of requisite variety is given by the interference of incremental technological change (Tushman and Anderson 1986) within regular maintenance work life with the exposure of employees to new equipment generations. However this factor does not influence all departments equally, since for example technological developments in SED are not frequent. Notwithstanding, the benefits for departments that are impacted are important. These departments reinforce a culture receptive to change in working practices and flexible to environmental fluctuations, and develop preventive maintenance skills and routines (Cohen and Bacdayan 1994; Nelson and Winter 1982; Nonaka et al. 2001a) and in particular routines on how to learn from these frequent changes. In addition, personnel from these departments are also motivated by the opportunity to learn and apply something new.

Besides job rotation and technology as requisite variety promoting factors, an obstacle for the realization of this condition is set by the organizational structure of the MD, which is neither flat nor flexible, since its numerous levels are linked to seniority, salaries, professional rights and academic qualifications, preventing the adaptation to various internal and external changes (Lessem 1998; Lessem and Palsule 1999; Nonaka 1994). This rigidity is reflected in the only major structural adaptation of the business layer (Nonaka 1994) allowed in the case organization, the reproduction of hierarchical levels and departments, such as, for example, with the division of the old Department of Mechanical Equipment.

However, requisite variety is obstructed not only by the structure itself, but also by the structure's combination with an information network incapable of eliminating information differentials and incapable of providing individuals with fast and equal access to a wide range of vital information (Peters 1987; Nonaka 1994; Nonaka and Takeuchi 1995; Nonaka et al. 2001a). The research showed that the existing information network is also complex, mainly informal, and its information flows are influenced by power relationships (Sheppard and Sherman 1998).

Moreover, the potential role of ICT for the creation of a virtually flat organization (Brown and Duguid 2000), where knowledge transcends boundaries, is ruled out since the existing ICT applications, the CMMS and the CWMS, operate in isolation in the PD and the WD respectively.

The case of the PD is indicative of these problems, since despite personnel's knowledge of where vital and up-to-date information for the proper performance of their duties is located, this information is inaccessible, due to the lack of competence trust (Newell et al. 2002) and the difficulty in interacting with other departments on equal terms. Hence, the PD is unable to respond accordingly to environmental changes by producing global interpretations of the situations and accurate maintenance plans.

7.2.6 Insights about the knowledge vision

The lack of either an official mission statement or official objectives of any kind deprives the MD from a knowledge vision (Von Krogh et al. 2000a) for the guidance of its activities, the coordination of the know-how creation process, and the shaping of an integrated culture.

A practical contribution is the identification that the close attachment of the case organization to its existing reality (Peters 1987; 1990b; Von Krogh et al. 2000; Nonaka et al. 2001a) is an important reason that prevents both the shaping and the communication of a sound knowledge vision. This attachment dictates a reactive mode of operation with a relatively short time horizon and a lack of competitive awareness (Von Krogh et al. 2000). The feeling of invulnerability within Petrochem is maintained by the small market size, the employment of highly skilled personnel, and the financial security ensured by protective state auspices.

Nevertheless, and despite the absence of a concrete knowledge vision, the research identified some elements of this in the organization. Hence, the organizational intention (Zack 1999a) is described by the existing corporate vision and recently introduced company-wide policies, such as the social responsibility policy. Although these are not very well-communicated, they clarify the company's purpose (Garratt 2001a) in a rather equivocal manner (Von Krogh et al. 2000) allowing employees to take different and often new leads during their activities. Furthermore, they often guide environmental activities and reinforce links to various groups and communities, enhancing commitment (Kalleberg et al. 1996).

Despite the fact that goal clarity is frequently limited and fails to commit maintenance employees to a common target (Von Krogh et al. 2000), within the MD the maintenance knowledge creation process is guided by unofficial embedded directives and supported by equivocal methodologies for goal achievement (Von Krogh et al. 2000a), which encourage creativity and assist new knowledge creation, since they allow multiple interpretations. Different interpretations enable the different framing of problems for the provision of appropriate, and often innovative, solutions. These directives both define the kind and domain of knowledge the company should create (Von Krogh et al. 2000) and direct the transformation of the current knowledge and task system (Von Krogh et al. 2000). The directives also reflect the existence of the national cultural trait of uncertainty avoidance (Hofstede 1991) and top managements' engineering culture (Schein 1996) that emphasizes safety issues. Moreover, the directives have embraced top management's persistence in redefining the organization in line with existing technologies and products rather than its knowledge base. They also reflect top management's absence in assuming a leading role in the dynamic facilitation of managing knowledge creation. Additionally, they signify the existence of an introvert value system that determines, evaluates, and justifies the quality of created maintenance knowledge with the basic criterion being the minimum interaction of the MD with other refinery divisions – in other words a reduction of participants in Ba.

Hence, the interpretation of these directives promotes the acquisition of maintenance skills (Drucker 1993; Nonaka et al. 2001a; Senge 1990b; Zander and Kogut 1995), often rare in Greek industry. This is achieved mainly through training, which increases employees' personal experience and facilitates the creation of context-specific knowledge and difficult-to-imitate knowledge assets (Teece 2001), such as maintenance know-how, adjusted to local operating conditions. The construction of the refinery substation network is an example of the creation of such difficult-to-imitate knowledge assets. This is also an example of overcoming existing hierarchical and structural boundaries, when top management - in a demonstration of competence trust in middle management - allowed them to act as merchants of foresight by introducing new technology.

Furthermore, the interpretation of the knowledge vision assisted some departments, such as the ED and the ID, to acquire preventive maintenance skills and to embed objectives for the development of a proactive mode of operation, which has become a basis for the development of routine knowledge assets in the form of preventive maintenance routines (Cohen and Bacdayan 1994; Nelson and Winter 1982; Nonaka et al. 2001a). Other departments, such as the WD created context specific knowledge in the form of policies that mitigate environmental fluctuations and avoid uncertainty (Hofstede 1991).

The leading role in interpreting and communicating these knowledge creating directives, mainly through personal interactions - both horizontally and vertically - is occupied by middle management, who learnt them in the form of informal objectives in the originating Ba of the morning meeting. Thus, engineers act as merchants of foresight fostering commitment and competence trust across employees. Middle management often set the example for the rest of the employees, when they act as "heroes" pursuing the realization of objectives. In doing so, they mobilize mechanisms that maintain and reward desired interpretations of the knowledge vision and fortify the organizational culture (Hofstede 1991). Their way of action is also assisted by the fact that Petrochem has always developed its own top managers from within the organization, who are thus acquainted with divisional objectives, while they have acquired similar experiences with the rest of the employees.

7.3 An analysis of the maintenance knowledge creation process.

7.3.1 Socialization, originating Ba and experiential knowledge assets

The socialization stage of the maintenance knowledge creation process involves not only the transferring and accumulation of tacit knowledge - often in the form of the experiential knowledge assets of maintenance skills and know-how, and mental models about maintenance repairs - but also the collection of social and other information from within or outside the case organization (Nonaka et al. 1994). This kind of information shapes the context within which the maintenance skills and know-how will be applied. The MD also provides frequent opportunities for sharing managerial and technical experiences, the acquisition of hands-on experiences (i.e., the acquisition of time- and space- specific tacit knowledge through practice), and the development of a worldview shaped from multiple and often contradictory perspectives.

This process has in fact a dual character, since it combines personnel socialization with maintenance skill acquisition, and is favoured by the protracted symbiosis of personnel within the refinery venues and the actual time they spend together daily throughout their career (Ivancevich and Matteson 1999). This symbiosis also gives employees the opportunity to share experiences and become acquainted not only with "success" stories, but also with diverse worldviews and opinions, while concurrently collecting "redundant" information (Wegner et al. 2002).

Shared history and maintenance experiences through this symbiosis, which are often coupled with the existence of common educational background, contribute to the development of a common understanding of maintenance work (Cannon-Bowers et al. 1993; Nonaka and Takeuchi 1995; Postrel 2002; Bechky 2003). This common understanding is reflected in the gradual development of a common language, practices, values and experiential knowledge assets by the microcommunities involved in the originating Ba of maintenance activities. Such an understanding facilitates and nurtures both inter- and intra- departmental interactions, which not only allow the acquisition of maintenance know-how and skills, but also the collection of valuable information and the exchange of experiences. Moreover, this kind of understanding is also a prerequisite for the participation in the Ba of the requisite variety enhancing opportunities, such as the construction of new units and personnel exchange trips, which assist the collection of intra-firm information and the transfer of know-how.

Nevertheless, the coexistence within Petrochem is rather coercive, since the privileged job security status of Greek public organizations in combination with the small petrochemical market leaves limited chances for career advancement. On the contrary, such an employment climate attracts various kinds of employees, who often manage to enter the organization. Personnel recruitment procedures, which could act as the first stage of socialization, anticipatory socialization (Feldman 1976; 1981), are not concerned with the achievement of a certain level of personnel conformity.

A contribution of the research is the explanation that in contrast to the practically non-existent anticipatory stage of socialization, the accommodation stage of socialization (Feldman 1976; 1981) appears to be extremely significant, since it facilitates the transferring and accumulation of internal knowledge (Nonaka et al. 1994) in the form of maintenance management and technical skills during job rotation. At this stage personnel test and build their mental models (Senge 1990b) on maintenance repairs. For low-level employees job rotation is coupled with apprenticeship, which requires their exposure to hands-on experiences and repair demonstrations and is their maintenance skill acquisition process (Drucker 1993; Zander and Kogut 1995).

Not only in the skill acquisition process, but also in the transfer and the collection of information, lower management play a protagonist role, taking advantage of their long-lasting employment. Having acquired skills and competencies that reach the expert level (Dreyfus and Dreyfus 1986), which provide them with the power of knowledge (Badaracco 1991; Introna 1997; Newell et al. 2002; Sinclair 1992), supervisors have gained both wide recognition as the most experienced group within the case organization and their colleagues' trust concerning their competencies. Consequently, the performance of the role of knowledge catalyst for lower management emerges naturally, when they regulate apprenticeship programmes by asking questions as to the skills missing in the refinery. Furthermore, supervisors act as connectors of knowledge initiatives by assessing the quality of acquired skills and by regulating their distribution amongst personnel.

Nevertheless, supervisors share a significant part of the burden of transferring maintenance skills and know-how to lower-level personnel, along with the facilitation of creating the necessary competence trust amongst technicians and their teams with senior technicians. This employee group complements lower management as a knowledge catalyst creating simultaneously both originating and exercising Ba in various demonstrations in the workshops.

The explanation that once technicians achieve an advanced beginner's stage of competence (Dreyfus and Dreyfus 1986), which is typically accompanied by official certification of their qualifications, they are allowed to participate actively in other types of Ba within everyday maintenance activities is also a practical contribution of the research.

Furthermore, apprenticeship, which takes the place of a general lack of any form of official training, is often coupled with mentoring (Ivancevich and Matteson 1999), especially in the case of middle management. Hence, senior engineers who mentor junior engineers play both the role of knowledge catalyst (by directing engineers towards specific technical and managerial skills), and of connectors to knowledge initiatives (using shared maps of cooperation and guidance), in order to bring together engineers in the departmental microcommunity and its culture, and to impart to them useful experiences.

Through apprenticeship and mentoring at the refinery fundamentally different experiential knowledge assets are acquired, diffused and transferred. Thus, some departments, such as the ED and the ID, focus on preventive maintenance skills and repair know-how, while others pass on skills and know-how about reactive maintenance. In fact the skill and know-how acquisition process within the case organization is nothing more than a multi-actor and largely tacit routine knowledge asset, an organizational routine, with two distinctive branches - a preventive one and a reactive one. This routine is set in motion primarily by the complementary performance of the knowledge activist roles by middle and lower management. Furthermore, this organizational apprenticeship and mentoring routine is also used for the acquisition of "rare" skills through face-to-face interactions.

The acquisition of technical and managerial skills occurs mainly at the beginning of an employee's career, creating some sort of a personal tacit knowledge repository. This accumulated tacit knowledge is not static, since it is updated from time to time depending on the position of the employee and on their personal intentions and motivation. Nevertheless, while these maintenance skills are a prerequisite for participation in the knowledge creation process, they work in combination with information flows concerning everyday working life. These information flows set the background for personal reflection and action.

Personnel from various microcommunities move within and across the boundaries of their team and their department and socialize with other participants, in both deliberate and spontaneous gatherings that occur during everyday working life in such places as the workshops and the refinery restaurant. These time- and space- specific face-to-face interactions create and energize the originating Ba, ensuring the necessary inflow of information and contributing to the formulation of ideas.

The originating Ba of the maintenance organization is supported to some extent by communications media, such as the telephone, while other types of media and ICT, such as video conferencing, are neglected, depriving the organization from virtual space for interaction.

Depending on the occasion, management (mainly middle and lower management) perform interchangeable and complementary knowledge activist roles by creating, participating in and regulating the originating Ba. In doing so, management connect local microcommunities, assist the flow and collection of information, the accumulation and transferring of tacit knowledge, and the building of the experiential knowledge assets, such as know-how and improvisation.

In the example of the morning meeting, the maintenance manager – perhaps the only official information channel of the MD with top levels - becomes a knowledge catalyst and a connector of knowledge initiatives by informing middle management about current corporate developments, by transferring the corporate vision and news about the company's operating environment, and by triggering the knowledge creation process, since he sets objectives. Moreover, this type of deliberate originating Ba interactions are strongly linked to the utilization of experiential knowledge assets, since they initiate first-level improvisations (Moorman and Miner 1998) to maintenance tasks without any formal analysis or planned decision-making process (Dreyfus and Dreyfus 1986; Crossman 1998; Crossan and Sorrenti 1997; Ciborra 1997; 2002) and only with basic knowledge of "the materials at hand" (Levi-Strauss 1967).

Furthermore, middle management's role as knowledge catalyst assists participation in other both spontaneously and deliberately created originating types of Ba, such as in the institutionalized workshop morning meeting with lower management. In these meetings engineers have the opportunity to share and accumulate tacit technical and managerial knowledge and experiences about maintenance work. The existing open-door system supports interactions between engineers and lower level personnel.

The role of lower management in these socialization interactions lies in the fact that they act as connectors of knowledge initiatives – or as carriers of up-to-date information - since they move between the refinery production units and the workshops.

Other interactions, such as those in the case of the WD, which initially emerged spontaneously, but then supported by management, cover the need for internal information collection and internal tacit knowledge transfer, even during crisis situations (Nonaka 1988a; Senge 1990b). Middle management, in an example of unconscious management of the knowledge creation process, which is also a practical contribution of the research, recognised and supported this kind of socialization by acting decisively as merchants of foresight without intervening in this exchange of knowledge and experiences. Hence, engineers allow workshop technicians to become connectors of knowledge initiatives by transferring workshop experiences and knowledge to warehouse personnel and increasing their understanding about maintenance craftsmanship. Moreover, workshop technicians act as knowledge catalysts, since their free movement around the company leverages personal experiences in a socialization process that also fosters feelings of care, sympathy and lenient judgement. Additionally, these socialization interactions at the WD shape redundancy of information, achieving overlapping skills (Von Krogh and Kameny 2002).

Moreover, in the socialization process, the employee union also plays a key role in facilitating the creation and sharing of tacit knowledge as a worldview (Nonaka and Takeuchi 1995). Concurrently, the union's activities, which are often supported by such media as newsletters and corporate magazines, foster high-care relationships. Top management, in the role of merchants of foresight, recognise and support both financially and morally the creation of originating Ba by the union in a deliberate effort to create consensus within the working environment.

Furthermore, the organization acquires and exploits external information and knowledge (Grant and Baden-Fuller 2000; Nonaka et al. 2001b) through face-to-face spontaneous and deliberate interactions with external microcommunities of suppliers, equipment manufacturers and contractors, who often provide insights about the market situation. These interactions offer opportunities for the establishment of information channels that transfer diverse experiences and enable the accumulation of know-how. These external information flows are maintained because of the potential financial benefits for these external parties. However, they create a co-evolutionary and symbiotic relationship (Nishiguchi 2001), since middle management, in the roles of merchants of foresight and knowledge catalysts, are given the opportunity to select technologies and applicable methodologies. This is also an indication that the information flow, in other words the SECI process, can determine Ba interactions. Furthermore, these information channels are also maintained through the building of companion and competence trust, and care. The contribution of supervisors is also important, since the research indicated that by performing the role of connectors of knowledge initiatives they connect the refinery with external microcommunities, often based on the criterion of competence trust.

Nevertheless, and besides the connection of skill acquisition and information collection with the existence of a common understanding on maintenance works, a common educational background, and a common history and maintenance experiences, indications show that involved interactions in this stage of the maintenance knowledge creation process are interwoven with the experiential knowledge assets of care, trust and improvisation (Ciborra 1997; 1999a; 1999b; Weick 1998; Moorman and Miner 1998; Nonaka et al. 2000a). These knowledge assets moderate originating Ba by creating boundaries with some characteristics of a community of practice, such as more or less permanent membership. These boundaries, which often limit participation in the socialization process, usually concur with the actual functional and divisional boundaries of the organization, since for example, and as the case of middle management indicates, during the accommodation stage of socialization (Feldman 1976; 1981) both competence trust and high-care relationships are mainly built intra-departmentally. Additionally, when low-care and competence distrust degenerate originating Ba, limited information collection and socialization occur. For example, this is evident in the interactions of the MD and the OD, where little recognition about the MD job prevents the sharing of experiences and mental models about repairs.

The research also indicated that experiential knowledge assets, such as companion trust are likely to be formed when originating Ba participants share elements of common identity (Wegner 1998), or have the ability to grasp the reality of others. This is evident in the deliberate and face-to-face interactions of the morning meeting, where participants are all engineers. These interactions fortify high-care personal relationships and build companion trust amongst top and middle management, while creating favourable conditions for the exchange of knowledge and the flow of information.

The performance of knowledge activist roles not only contributes to the maintenance or overcoming of boundaries, but is also associated with the creation and the utilization of experiential knowledge assets, such as skills, know-how and trust. For example, lower management distrust top management's role as merchant of foresight and perceive this as a sign of low-care and indifference. Similarly, middle management sometimes treats supervisors that act as knowledge catalysts and move freely, with relative distrust and suspicion. Conversely, OD middle management act as connectors of knowledge initiatives when they encourage and trust the participation of the MD in non-maintenance activities.

In addition, and despite the relative tendency of knowledge assets, such as care and trust, to formulate and diffuse horizontally, enabling a parallel flow of information amongst individuals of each hierarchical level, frequently the experiential knowledge assets within the case organization overcome intra-departmental and intra-divisional boundaries through the contribution of other experiential knowledge assets. For example, companion trust, connected with feelings of empathy (Von Krogh 1998) and coupled with high-care relationships, exists between low-level Petrochem and contractor personnel, ensuring the exchange of knowledge.

However, when it comes to professional relationships, in particular at higher levels, the development of experiential knowledge assets, such as competence trust, beyond departmental boundaries is concurrently strongly vested with tangible and intangible benefits and motives. This happens in the case of know-how transfer through socialization with colleagues from the other refineries of Petrochem. Additionally, OD middle management in a relative demonstration of competence trust support the involvement of the MD in the construction of new units, since they are benefited from it. When the potential benefit for the OD ceases, its lower level employees in a demonstration of low-care transact important knowledge (Von Krogh 1998) for maintenance works with the MD.

As far as the experiential knowledge asset of improvisation is concerned, the research indicated that it often creates value for the company and that it is connected both to emergent and deliberate types of originating Ba. For example, the morning meeting of middle management allows improvisational high-level adjustments and re-prioritizations of activities in the maintenance plan (Crossman 1998; Weick 1998; Moorman and Miner 1998). Similarly and complementary to the engineers, lower management act as connectors of knowledge initiatives by changing and rearranging the activities' sequence within a work in progress (Crossman 1998), while warehouse-technicians construct and modify spare parts in an demonstration of improvisation in the form of tinkering (Levi-Strauss 1967; Ciborra 1997; 1999a; 1999b). Such actions are feasible since personnel utilize internal information collected from their face-to-face interactions allowing them to interpret conditions accordingly.

A contribution of the research concerning the experiential knowledge asset of trust, which so far has been implied, is its distinction with respect to companion and competence trust and its association to the maintenance knowledge creation process by demonstrating its development process, its interrelation to other assets and its moderating impact upon human interactions.

Perhaps a more important contribution of the research is the provision of insights that underpin ideas about the distinction of experiential knowledge assets into two major categories - positive and negative. In accordance with the literature, which differentiates between "good" and "bad" improvisations (Ciborra 1999b) and high- and low-care relationships (Von Krogh 1998), the research identified in the case of the PD the existence of mistrust, which extends beyond a simple lack of competence trust and care or even the existence of distrust, which is evident in the example of the WD operation and is also accompanied by lenient judgement (Von Krogh 1998). Mistrust, as an output of the socialization stage of the maintenance knowledge creation process and as an example of negative experiential knowledge asset, not only lacks the solid foundation created by the development of a common understanding amongst participants, but also its existence is justified by past experiences that perceived differences cannot be bridged.

Furthermore, such a distinction of knowledge assets could provide a potential explanation of the argument that the SECI process may result in a reduction of knowledge (Nonaka et al. 2000b). It could also link the concept of the knowledge conversion rate (Nonaka et al. 2000b) to knowledge assets, since the latter is responsible for the moderation, such as acceleration or deceleration, of the knowledge creation process. Additionally, and as the research indicated, negative knowledge assets could support the explanation of the performance (or not) of various roles within the knowledge creation process, such as the role of connector of knowledge initiatives by the PD during the planning and scheduling process. Moreover, a distinction of trust, care and improvisation into positive and negative experiential knowledge assets that are created at the socialization stage of the knowledge creation process could assist the interpretation of the moderating role of knowledge assets at all other stages of the SECI process.

7.3.2 Externalization, dialoguing Ba and conceptual knowledge assets

The externalization stage of the maintenance knowledge creation process is energized with the explication of personnel's tacit knowledge during maintenance repairs and other non-maintenance activities, such as in the example of the construction of the first private electricity production unit. In simple terms, tacit knowledge explication requires the utilization of existing maintenance skills and know-how for the repair of an equipment fault within a framework that has been shaped by inflows of information concerning the existing situation. The individuals' participation in the originating Ba of socialization is required for the acquisition of these information flows.

Within the MD the context for the externalization process, the dialoguing Ba, is synthesized by collective and face-to-face interactions, aimed at discussing and initiating reflection for the creation of ideas and hypotheses on actual or potential equipment faults. However, the boundary between the socialization and the externalization process is not very clear, since the fault identification discussions occur concurrently with socialization interactions, which ensure inflows of information about everyday maintenance activities.

Based on the most probable hypothesis concerning the equipment fault, dialoguing Ba interactions aim at creating a conceptual knowledge asset, the integrated repair concept, which describes fundamental elements of the repair. The dialoguing Ba also assists in sharing these repair hypotheses and concepts throughout the company.

The repair concept development process requires not only the interpretation of information and data, and the sharing of skills and mental models, but also the integration of this knowledge within the given context.

The externalization stage of the maintenance knowledge creation process is usually initiated when requestors of maintenance work identify a perceived problem that requires resolution through either preventive or reactive action. Requestors, by acting as knowledge catalysts, utilize their skills and know-how and ask questions about a plausible solution. In doing so they energize dialoguing Ba initiating discussions and collective reflections. Despite the fact that within the case organization everybody can request maintenance work, the research indicated that when this is done by lower management, possibilities for the creation of valuable knowledge increase. An explanation for this is that their ability to move freely within the refinery venues and to take advantage of the most important communication means, the wireless radio, allows them not only to simply identify a problem and request its resolution, but also to frame it in such a way as to provide clear directions for action by others. Since the maintenance knowledge creation process is not merely a problem solving process, in situations where interactions and discussions in the dialoguing Ba fail to frame the problem correctly, drawbacks are frequent.

A common language understood by all participants involved in the discussions, and the concomitant interactions, become the basis for communication (Nonaka 1994; Von Krogh et al. 2000a; Bechky 2003). Within the MD such a common language has gradually emerged due to the protracted socialization of personnel. It contains both technical terminology and other local expressions. This verbal language, coupled with non-verbal language, such as images and symbols, is important for the communication of requests for repairs and the fault identification process.

The importance of communication becomes evident during the process of the creation and crystallization of the knowledge asset of the repair concept (Nonaka 1994; Von Krogh et al. 2000a). This knowledge asset creation occurs gradually through a reciprocal process in which hypotheses about the potential equipment fault are formulated and rejected. Each hypothesis is linked to a number of repair options, which often have an innovative character and include elements of uniqueness, novelty and creativity (Hargadon and Fanelli 2002). However, very often the repair options are well-tested. In such cases the knowledge creation process degenerates into a process of re-justification of existing knowledge. The most probable hypothesis about the equipment fault that resists rejection becomes the crystallization core[61], a term borrowed from the natural sciences, the core around which the repair concept develops.

Besides the identification of the most probable equipment fault, the development of the repair concept requires the selection an appropriate repair linked to this hypothesis. During the development process of the repair concept dialoguing Ba, interactions act also as a filtering process or as a bottleneck. Such filtering can be perceived as a first stage of the knowledge justification process, which frames the problem and defines the background of the solution that will be provided. This process also promotes self-reflection and the transcendence of boundaries, since the dialoguing Ba uncovers to its participants more facts and information and articulates knowledge. Thus, very often during discussions some of the hypotheses, along with their repair options, are rejected since they do not fulfil financial, legislative or other kinds of criteria. Hence, the research indicated that the application of these criteria constitutes a reflective type of knowledge justification. Then, after this first kind of justification in reflection, the repair concept needs to be justified in action during the internalization stage of knowledge creation. The identification of two distinctive steps in the knowledge creation process for the justification of knowledge, which also indicates the continuity of the SECI process, is an additional contribution of the research.

Another indication from the research concerning the continuity of the SECI process is the fact that decisions taken during dialoguing Ba discussions contribute to the identification of other

[61] A common phenomenon in the field of electrochemistry is the phenomenon of crystallization of chemical substances on electrodes in aquatic solutions under the influence of an electrical field. Crystallization cores are certain points of the electrode upon which the crystallization process starts. As in electrochemistry not all cores are used for the crystallization of the substance on the electrode depending on the local conditions of the solution microenvironment, not all hypotheses about potential equipment faults will become actual concept crystallization cores.

subsequent types of Ba. Thus, for example, the decision about the repair location, which is taken by senior technicians during the externalization stage, defines the exercising Ba in which personnel will justify or reject the repair concept and people will have the opportunity to participate and access the created knowledge.

In general, the reciprocal process of dialoguing Ba discussions and interactions is nothing more than a well-established routine knowledge asset, which guides the externalization process and can formulate two fundamentally different kinds of repair concepts related either to preventive or to reactive maintenance. Hence, the routine knowledge asset, which is set in motion during fault identification cases and directs the organization's capacity to act, has two branches that the knowledge creation process follows, depending on whether personnel use preventive or reactive maintenance skills. Their basic difference lies in the fact that repair concepts concerning preventive maintenance are much more integrated than those concerning reactive ones. This is due to the fact that dialoguing Ba interactions for preventive maintenance are not so time urgent, allowing intense reflection on the incident at hand. Therefore, personnel have the opportunity to invite and contact participants and to access information. Hence, the focus of discussions for preventive repairs differs significantly from the focus of discussions for reactive maintenance. Furthermore, preventive repairs are much more organized and people are motivated to participate.

Time appears to be an important issue in the dialoguing Ba due to its influence upon knowledge articulation and upon collective and face-to-face interactions, since it defines the number of meetings and site visits. Time restrictions also obstruct reflection and the necessary articulation of knowledge back to the individuals. The minimization of this kind of information flow undermines the quality of created knowledge, since the fault identification process is often a tedious and time-consuming task that requires the integration of knowledge.

Furthermore, the just get-it-done environment within the case organization allows limited time to dialoguing Ba interactions, when it comes to already known maintenance incidents. Therefore, once the organization creates knowledge about a particular repair, personnel are not given the opportunity to reflect on this in order to improve it further and in doing so they do not re-justify the truthfulness of previously acquired and created knowledge.

The research indicated also that time restrictions bring forward the impact of the experiential knowledge asset of improvisation upon the development of repair concepts, since personnel in a form of tinkering (Ciborra 1997; 1999a; 1999b; Moorman and Miner 1998) take different leads according to the circumstances without any previous formal analysis. However, personnel's pursuit does not aim at a better solution, but at a faster solution and this reflects the relative absence of the role of the merchant of foresight who might otherwise provide short-term direction.

Only after the crystallization of personnel's explicit knowledge concerning an identified equipment fault can this knowledge be shared by others and either re-justify existing knowledge or become the basis of new knowledge at the later stages of the knowledge creation spiral. The written version of the conceptual knowledge asset of the repair concept, the WO, represents the official channel for such knowledge articulation, and often misses explicated knowledge concerning minor maintenance activities.

Both the shared map of cooperation, the MWOS, which is responsible for the creation and utilization of the conceptual knowledge asset of the WO, and the WO itself, appear to be rather inflexible when it comes to following and describing the reciprocal process for the development of the repair concept (Nonaka 1994). Consequently, value-adding information flows often remain within departmental boundaries (e.g., information from the automated preventive maintenance programme), and escape the process of synthesis and crystallization of the repair concept, contributing to its impoverishment. Nevertheless, conceptual knowledge assets concerning preventive maintenance are better adapted to this reciprocal process and are much more complete and organized since there is adequate time to integrate more information flows successfully. In contrast, cases of reactive maintenance fail to integrate information flows and this is reflected in the fact that for some repairs, more than one conceptual knowledge asset are created and coexist. This is also an indication of the lack of somebody who could play the role of knowledge catalyst for the creation of dialoguing Ba, which would facilitate knowledge integration.

Besides the MWOS, the use of other shared maps of cooperation (Butler 1996) within the case organization appears also to be limited, if non-existent, since there is lack of a structured method for fault identification. Hence, the externalization process for the repair concept is not only somewhat heuristic (Nemeth and Nemeth 2001), but also discussions often lack focus (Scarbrough and Corbett 1992). Furthermore, middle management fails to become a merchant of foresight by not promoting methodologies or techniques to structuring these discussions (Von Krogh and Roos 1995; Von Krogh et al 2000a).

However, and despite the relative absence of shared maps of cooperation for the facilitation of conversations, this perceived gap is covered by the frequent use of the metaphor/analogy mechanism (Bateson 1979; Donellon et al. 1986; Tsoukas 1991; Nonaka and Takeuchi 1995) that enables transferring tacit knowledge, concepts, ideas, meanings and explanations. Moreover, the use of the metaphor/analogy mechanism can stimulate reflection that will make the individual re-examine former concepts about repairs and mental models, since it associates previously acquired knowledge with current situations, which could be similar, but not necessarily the same as the old ones. Thus, this mechanism does not only facilitate knowledge creation, but also enables common problem solving, since personnel recognize similarities between everyday situations and sometimes apply ready or slightly modified solutions. The case of the blocked pressure relief valves is such an example, and one that also highlights the prominent role of supervisors as knowledge catalysts who triggered the collective reflection of an autonomous departmental team on a real-world problem. The use of the metaphor/analogy mechanism through dialogue facilitated the generation of an intuitive solution by "rational thinking and by focusing on functional similarities and differences" (Nonaka and Takeuchi 1995) resulting in the creation of a new concept, similar to the case of Canon (Nonaka and Takeuchi 1995). However, even with the use of this mechanism, such knowledge-creating cases often result in bounded knowledge dissemination, since knowledge remains within the team that dealt with the problem.

An additional indication of the research is that the frequent use of the metaphor/analogy mechanism is facilitated by the complementary performance of the knowledge activist roles by various management levels. These roles enable the communication of information about the development of repair models often using analogies from similar or other relevant incidents. Thus, in the example of the first private electricity production unit, top management (in the role of the merchants of foresight) gave the general direction, while middle management (in the role of connectors of knowledge initiatives) interpreted the situation and came up with a concept that would fit the local operating conditions.

Hence, participants in dialoguing Ba manage to bring together different kinds of knowledge (Doyle 1999) from their microcommunities with the support of those who perform, often in complementary way, the role of connectors of knowledge initiatives, as the example of pump repairs at the RED demonstrated. In general, lower management occupy a decisive part in the role of the connectors of knowledge initiatives. Supervisors control interdivisional and interdepartmental interactions of deliberate dialoguing Ba by influencing the mix of specific knowledge and capabilities, when they create the non-standardised fault identification team. The creation of this type of Ba is based on the existence of competence trust and on the perception that the participant has a certain level of understanding regarding technical issues. Moreover, and besides the development of a common understanding, the sharing of common experiences, history and educational background frequently appear to be decisive factors for the common participation in dialoguing Ba, as fault identification interactions between the ED and the ID indicated. In addition, not only do supervisors make the first important decisions concerning the creation of the repair concept, but they also often approve the executed work as the example of quality control indicated. This role is performed with the support of the most important means of communication in oil refineries, the wireless telephone system.

Besides the selected, by lower management, participants in dialoguing Ba, rare or unusual cases attract motivated and committed individuals, who voluntarily involve themselves facilitating the knowledge creation process by ensuring the articulation of knowledge (Doyle 1999). Such involvement not only enables self-improvement and advancement to higher levels of competence through the development of a broader understanding of technical issues and through individual self-reflection (Scarbrough and Corbett 1992), but also indicates the effectiveness of the existing informal communication network in the diffusion of information.

The already acquired tacit knowledge in the form of managerial and technical skills and know-how gives personnel the confidence to deal intuitively with this externalization process. Additionally, knowledge inflows provided by various participants reduce uncertainty.

The role of middle management during externalization is equally important (Naito 2001). By acting as knowledge catalysts, when they move freely to various dialoguing Ba and when they ask questions about financial, technical and other issues, they influence maintenance knowledge creation. Thus, for example, their questions contribute to the approval or the rejection of the repair concept, while they often set the background for the provided solution. In addition, middle managers in the role of connectors of knowledge initiatives regulate high-level interdivisional and external knowledge communication. Moreover, the case of the blocked pressure relief valves reflects their action as merchants of foresight, since they promoted the dissemination of knowledge produced by the experimentation of the supervisors' autonomous teams. In the same role middle management interpret and also communicate the vision or other objectives of the MD, and in doing so they direct the knowledge creation process.

Nevertheless, the research also indicated that the performance of the knowledge activist roles is not always successful. Hence, the PD, which is responsible for the utilization of the shared map of cooperation of the MWOS, fails to play the role of connector of knowledge initiatives. The fact that the PD does not enjoy strong competence trust of other colleagues contributes to the lower performance of this role. Consequently, this cooperation map fails to create deliberate dialoguing Ba by becoming an important means for the management of conversations, while more often than not information flows escape it.

However, the failure in performance of the role of connector of knowledge initiatives by the PD reveals a power of knowledge game with the competing group that has successfully played this role within the case organization. Thus, when lower management act as connectors of knowledge initiatives, they often withhold information. To a certain extent the escape of valuable information flows from synthesis of the conceptual knowledge asset of the WO can be attributed to time restrictions on the supervisors. However, the influence of low care, which becomes apparent through the lack of lenient judgement and the tendency of lower management to transact knowledge during their interactions with the PD, the manager of the WO conceptual knowledge asset, is more important. Thus, the flow of information between the source, the supervisor, and the receiver, the PD, is obstructed, since the PD (as participant in dialoguing Ba) does not share a common understanding and background with others due to lack of similar episodic[62] (Swap et al. 2001) and procedural[63] memories (Cohen and Bacdayan 1994). Thus, planners do not understand the information flows they have to record and integrate in the WO. This lack of understanding contributes to the lack of motivation to participate in dialoguing Ba and their role becomes primarily transactional (Von Krogh 1998), since they receive information as is, and are not in position to question its value and reliability. In addition, the lack of care is evident, since supervisors do not devote some of their time for explanations and they do not offer help. The same problem occurs during the description of the executed works, where the use of language turns out to be inadequate. Then, the PD again fails to become a connector of knowledge initiatives, since it does not understand much of the provided information and therefore it neglects it. In addition, low care relationships encourage other participants in dialoguing Ba to transact knowledge simply by minimizing information flows towards the PD, which is not particularly trusted.

Moreover, this situation reflects the relative failure of the role of merchant of foresight at all management levels. Hence, lower management neglect and underestimate the knowledge asset of the WO. In some cases the conceptual knowledge asset of the WO is overlooked, since the project layer, meaning the workload of some departments, does not justify its use. While middle management recognize the potential role of WOs for building systemic knowledge assets, such as the equipment history database, they have difficulties in acting as merchants of foresight and convincing supervisors about the potential usefulness of a working system with enhanced WOs. These difficulties can be attributed to the relative success of the established organizational routines and utilized practices by supervisors. Moreover, a working system with enhanced WOs

[62] Episodic memories are memories of events directly experienced.

[63] Procedural memories are knowledge "for how things are done"

would require the PD to become the manager of a knowledge repository (Earl 1994a) consisting of completed WOs, meaning the manager of the created organizational knowledge. The research indicated that maintenance personnel find the visualization of such an approach difficult.

However, the example of the relative exclusion of the PD from dialoguing Ba with the contribution of the experiential knowledge assets of low-care and mistrust, which shows a not so open character of dialoguing Ba, is not the only one. The research indicated that other groups, such as the OD, do not play a very active role when it comes to providing information. Thus, interactions of the MD with the OD are simple information transactions concerned mainly with time flexibility. The limited participation of OD in dialoguing Ba contributes to the creation of pure conceptual knowledge assets, due to the reduction in information flows.

The impoverishment of the conceptual knowledge asset also occurs because of personnel's difficulty in providing vital information before and after the execution of the work through the use of verbal and non-verbal language, reflecting a weakness of this means of communication. Besides insights from the initiation of maintenance work, other examples of tacit knowledge explication, such as the recording of the executed maintenance work and the provision of feedback about the quality of the work, indicated that, due to language weaknesses, the maintenance repair knowledge often remains in a tacit form at the team, which dealt with the problem.

The lack of standardised maps of cooperation makes the establishment of an official feedback information flow even more difficult, while the relative lack of the role of merchant of foresight, who could introduce such maps for the articulation of tacit knowledge gained at the workshop, contributes to the maintenance of this problem. In addition, middle management's attachment to a "just get it done" approach destroys any opportunities for the creation of this type of dialoguing Ba. The situation also indicates the development of little understanding about the potential importance of this externalization process and reflects lack of provision of a clear knowledge vision (Peters 1987; Von Krogh et al. 2000a) by top management.

In some other cases, already existing systemic knowledge assets, such as national standards, obstruct the integration of information flows, such as in the example of the ED where standards deprive the recording of information about the performed work on the JP, contributing to the degeneration of the externalization process.

Finally, the research indicated the rather limited support to the conceptual knowledge asset of the WO by pre-existing systemic knowledge assets, such as databases, and by the existing ICT infrastructure (Davis and Nauman 1999), which fails to ensure a communication channel for information inflows and the articulation of explicated knowledge, and for the connection of local microcommunities.

Consequently, within the case organization, WOs - as firm-specific tangible conceptual knowledge assets - create limited value (Bukowitz and Williams 1999). This is due to the fact that the explicit knowledge complexions of the crystallized repair concept contained in the WO – meaning the description of the maintenance repair - make expected services difficult to derive from them (Boisot 1995; 1998; Teece 1998). They also deprive people without contextual knowledge from utilizing them, since such knowledge assets are not habitat-free and their articulation is difficult (Boisot 1995).

7.3.3 Combination, systemizing Ba and systemic knowledge assets

Following the natural flow of maintenance works at the refinery, the research approached the combination stage of the maintenance knowledge creation process through the maintenance planning and scheduling aspects of the case.

The planning and scheduling function is a process of internal and external explicit knowledge acquisition, synthesis, editing, and processing for the formation of new complex sets of explicit knowledge. This maintenance function requires first the interpretation and then the decomposition of the crystallised (i.e., authorised), maintenance repair concept, before its integration and synthesis with other sources of explicit knowledge for the creation of systemic and explicit knowledge on the repair to be performed. In the case organization the systemic knowledge asset of the JP is representative of this stage of the knowledge creation process.

The investigation indicated that the combination stage of knowledge creation, which in the planning and scheduling function is perceived as identical to the development process of the JP, occurs according to a routine knowledge asset that directs actions and interactions. This routine knowledge asset is a multi-dimensional organizational routine (Nelson and Winter 1982; Cohen and Bacdayan 1994) and is based on the assumption that the PD cannot act as connector of knowledge initiatives, and consequently cannot plan and schedule. The frequent narration of stories, which present lower management as heroes (Schein 1985), who save the situation, act as a conformance mechanism (Levitt and March 1988; Szulanski 2000) and contribute to the maintenance of this routine.

In general the research indicated that the routine pertaining to the planning and scheduling function comprises two branches that relate to a preventive and a reactive mode of operation of the combination stage respectively. Thus, this theoretical contribution of the research explains that the two modes within the same stage of the SECI process influence all three elements of the knowledge creation process; the nature of information flows and the way these are utilized (or not), the context of the combination process, meaning the interactions, and of course the associated knowledge assets. In addition to the two identified branches of the combination process the research demonstrated the co-existence of cases that combine characteristics from them both that enrich the organizational routine.

However, either in proactive or in reactive maintenance, the systemic knowledge asset of the JP appears as a non-fully integrated set of explicit knowledge. An explanation for this is that the core of the JP is occupied by the somewhat degenerated conceptual knowledge asset of the WO that fails to link all other related information. Furthermore, the non-fully integrated JP indicates the lack of the role of the merchant of foresight, who might otherwise convince personnel about its use. This example also demonstrates a link between the concept of Ba and the concept of knowledge assets, since Ba interactions can influence the creation of knowledge assets, which in turn moderate the SECI process with their rich or pure information content.

The coexistence of different modes of knowledge conversion at the combination stage becomes apparent not only in the collective and virtual interactions and the use of virtual media within systemizing Ba for the acquisition, synthesis and processing of explicit knowledge, but also in the availability and use of the sources of explicit knowledge, as the extreme cases of the ED and the PD indicate.

The case of the ED, which presents an example of successful planning and scheduling, is representative of the proactive branch of the organizational routine of combination. This example indicates that a successful combination stage involves multiple, collective and virtual interactions supported by media, which create and utilize various systemic knowledge assets. Thus, the ED along with other departments that deal with proactive maintenance (e.g., the ID) produce enriched JPs by combining explicit knowledge in a companion trust environment.

Middle management actively play the role of the merchant of foresight by promoting the selection, acquisition and exploitation of sources of explicit knowledge. In the ED, middle management introduced ICT, enabling the creation of systemizing Ba for the collection of explicit knowledge from the OD. In doing so middle management managed to by-pass the rather painful low care face-to-face interactions with the machine operators that were characterized by mistrust. Moreover, ICT enabled the creation and synthesis of two systemic knowledge assets, namely the performance reports and their associated database, which contribute to the development of an information-enriched JP by setting the job specifications. Nevertheless, the introduction of ICT by the ED required the development of an understanding about its potential use, which was boosted by an increase in the workload of the department, meaning in its project layer (Nonaka 1994).

Furthermore, the investigation indicated that the effective proactive planning and scheduling of maintenance works is enabled by the active performance of middle management in roles associated with knowledge activism. Middle management, with their preventive maintenance skills, and know-how, play the knowledge catalyst role in combination with support gained from the shared map of cooperation of the equipment Condition Monitoring Methodology. This map directs the utilization of available internal and external sources of explicit knowledge. Thus, middle management's action triggers combination at least in a threefold way. First, they take advantage of the systemizing Ba provided by ICT (Davis and Nauman 1999; Alavi and Leidner 1999; 2001) for the production of complex systemic knowledge assets, such as reports. Then, they forecast imminent faults deviating from the context-free explicit knowledge provided by manufacturers, thereby enabling cost reductions since unnecessary maintenance is avoided. Finally, they ask questions concerning the evaluation of the routine knowledge assets in the form of established maintenance working practices and repair organizational routines. For example, in the case of the ED the performance report database provides the necessary explicit knowledge for the development of more effective maintenance working practices.

Furthermore, preventive maintenance, both in the ED and the ID, have created and contributed to the maintenance of AR databases, indicating that often the condition of systemic knowledge assets is associated with their utilization. Thus, either because working practices require it or because information of departmental AR databases is utilized for the synthesis of more complex knowledge assets, lower management in ED and the ID, perform the role of knowledge catalyst with regard to database maintenance and registration activities. This is also an indication that the knowledge creation process creates knowledge assets, where these are needed. In contrast to examples of limited use of the explicit knowledge of AR databases, such as in the case of the SED, middle management, as merchants of foresight, encourage and assist activities concerning the maintenance of the database, since they have developed an understanding about its value. However, even in those cases where utilized departmental databases are used, the quality of information varies greatly depending on the frequency of use. Additionally, this reflects the relative lack of a shared map of cooperation, such as common database management guidelines, and the failure of merchants of foresight to promote their use.

Furthermore, the shared map of cooperation of the Condition Monitoring Methodology allows both ED middle and lower management to act synergistically as connectors of knowledge initiatives by acquiring and synthesizing knowledge from sources, such as the AR database, for the creation of systemic knowledge assets, such as the Job Plan, and for their dissemination within or across departmental boundaries. Their actions often initiate further synthesis and processing of explicit knowledge in more complex assets. For example, middle management devote much time to the synthesis of various explicit knowledge sources for the preparation of feasibility studies. They consider this activity as the essence of the engineering job, and is often used as a knowledge source for other knowledge assets. By acting as merchants of foresight with the provision of a clear direction, middle management overcome problems in the synthesis and processing of explicit knowledge. The development of an increased level of understanding concerning the combination process, due to their high education background, not only allows lower management to support and realize middle management's intentions, but also to provide effective guidance to the low level autonomous teams.

Figure 7.1 presents how middle and lower management perform the knowledge activist roles, not only during the combination stage of the maintenance knowledge creation process, but also throughout the whole process. The same figure also points out that within the ED and the ID there is often synergistic action between these two management levels in contrast to the other two departments that execute maintenance work, the SED and the RED.

Figure 7.1 **Performance of the Knowledge Activist Roles**

Department	ED	ID	SED	RED
Middle Management				
Knowledge Catalyst	Active	Active	Not very active	Not very active
Connector of Knowledge Initiatives	Active	Active	Not very active	Not very active
Merchant of Foresight	Active	Active	Not very active	Not very active
Lower Management				
Knowledge Catalyst	Active	Active	Very Active	Very Active
Connector of Knowledge Initiatives	Active	Active	Very Active	Very Active
Merchant of Foresight	Active	Active	Very Active	Very Active
Synergistic action between middle and lower management	Yes	Yes	Limited	Limited

Knowledge combination in proactive maintenance recognizes that the organizational routines of job execution are inseparable from the synthesis of JPs. In such cases lower management act successfully as connectors of knowledge initiatives, providing concurrently, as in the example of the ID Crew Coordinator position, the required information that covers for the weaknesses of the JP. The same example is also another practical contribution of the research, which demonstrates a successful adaptation of the business layer for the accommodation of the needs of the project layer (Nonaka 1994) within the knowledge creation process. Similarly to the ID, the case of the ED shows that lower management and their crews, which are responsible for the operation of the substations, ensure the constant inflow of information not only before the occurrence of the fault, but also during the planning and scheduling phase.

On the other hand, in the combination stage of reactive maintenance, things differ significantly from the ED and the ID. More specifically, the example of the PD, which should manage the planning and scheduling function for the MD in normal circumstances, demonstrates a case of degenerated systemizing Ba comprised of impoverished and transactional collective interactions that lack the support of media. This justifies the relative failure of the PD to become the manager of the systemizing Ba of the planning and scheduling function for the whole case organization, since the interactions in which PD personnel participate are neither created, nor regulated by them.

The acquisition of declarative knowledge or "know about" (Brown and Duguid 2001) enables the PD employees to have a supportive role as knowledge catalysts by breaking down, namely interpreting, the repair concepts in planning and scheduling. However, planners bump into difficulties when it comes to the use of the necessary shared maps of cooperation for the acquisition and integration of explicit knowledge, sometimes due to lack of training. Indicatively, the inconsistent use of the shared map of cooperation of the work priority system allows multiple and often contradictory interpretations of the criticality of each JP, which is necessary for scheduling maintenance jobs. This ambiguity contributes to the creation of a sense of crisis that destroys the efforts for the creation of a maintenance schedule.

Moreover, another shared map of cooperation - the MWOS - is based upon the standalone CMMS. Hence, ICT fails to establish communication channels not only for the inflow of information to the PD, but also for access to the information of this isolated application to other departments. Thus, the lack of ICT support to the systemizing Ba interactions of the PD poses an additional difficulty to its personnel in acting as connectors of knowledge initiatives.

In contrast to the ED and the ID, which use ICT according to their proactive maintenance needs, the absence of strong ICT support to the systemizing Ba of the PD contributes also to the underutilization of departmental systemic knowledge assets in the form of databases that could become an additional source of explicit knowledge. Thus, the systemic knowledge asset of the CMMS AR, which should contribute to the creation of JPs, accurate reports, and historical records, suffers from a number of data and information quality problems (Davenport 1997; English 1999; Eppler 2003), since often its entries, similar to the entries of the CWMS spare parts database at the WD, lack precision and accuracy. Cases of unreliable entries are not at all rare. Consequently, the CMMS AR not only cannot be used for the extraction of useful information, such as the evaluation of adopted maintenance practices through the utilization of historical records, but also cannot support the internalization stage of knowledge creation, since it cannot adequately facilitate the dissemination of the created explicit knowledge sets.

Additional indications are that unresolved issues of ownership and management (Davenport 1997; English 1999; Eppler 2003) within the MD are also linked to the creation and utilization of the database knowledge assets. The formation of many polymorphic departmental AR databases is an indication of the coexistence of power kingdoms and can be seen, at least partially, as an ownership problem. The reduced competence trust towards the PD to manage an integrated and validated AR database also contributes to this situation.

In addition, the research indicated that, with the exception of financial reports, small feasibility studies and the preparation of maintenance manuals, interdepartmental or interdivisional reporting is not a popular way of communication for top and middle management, who make decisions based on knowledge acquired during socialization. The creation and utilization of reports is primarily limited within hierarchical and functional boundaries. However, in reactive maintenance this kind of communication and articulation of knowledge is even more reduced. For example the low care relationships between the PD and the OD limit the articulation of reports only to the transactional transfer of the maintenance backlog.

In fact and in the absence of value adding databases and ICT support, the maintenance backlog is the only report produced regularly by the PD. This systemic knowledge asset replaces in the degenerated combination process at the PD of the systemic knowledge asset of the maintenance schedule. The difficulty in delivering of a daily or even weekly maintenance schedule by the PD can be attributed, to a great extent, to the lack of integrated JPs, which obstructs any further synthesis into the more complex maintenance schedule.

In addition, reactive maintenance does not favour the combination of explicit knowledge. For example, while the ED receives accurate information, not only from its AR database, but also from reports and various other sources, the PD receives information in the form of verbal estimates. Despite the fact that these estimates are explicated knowledge, their form does not allow further integration. Therefore, the PD personnel are unable to respond to real world situations as connectors of knowledge initiatives, since their action would require the integration of these estimates and they lack of an understanding of the organizational routines associated with maintenance execution.

Within the planning and scheduling organizational routine this relative role gap is covered by lower management of other departments, not only in reactive, but also in proactive maintenance. Thus, lower management, equipped with the necessary dispositional knowledge and expert skills, act as connectors of knowledge initiatives and exploit updated information and sources of explicit knowledge, even in the form of estimates, in order to plan and schedule. In doing so they are supported by the wireless telephones. Moreover, lower management disseminate the newly created sets of explicit knowledge, such as the JPs. In this way, supervisors demonstrate their very good knowledge of the microcommunities to be connected and their understanding of the risks involved in each repair concept.

Lower management's role also allows them to bring new information, which frequently enables the initiation of improvisational changes to the scope of the maintenance work, the repair concept. This appears as an important undermining factor in relation to the efforts to acquire and synthesize explicit knowledge by the PD. Such changes, which are more frequent in reactive maintenance, reduce the available time to identify and utilize explicit knowledge sources, and limit opportunities for their further synthesis and integration. As a result this impoverishes JPs. Additionally, the changes to the scope of work often reflect that dialoguing Ba interactions were not effective, since sometimes they result in wrong fault identification. Other times, changes indicate the fact that the crystallization of the repair concept does not terminate dialoguing Ba interactions, and these continue after the combination stage has started, revealing information that often changes the situation at hand radically.

In addition, and especially in departments with a rather simplified project layer, such as in the SED where the vast majority of the workload concerns the welding of pipes, JPs are even more impoverished in terms of explicit knowledge complexions. In such cases lower management neglect the potential use of complex JPs during the organizational routine of maintenance work execution. When this is contrasted to the situation at the ED, the conclusion that can be drawn is that across the organization the wide spectrum of diverse treatments of this knowledge asset reflect the development of different levels of understanding concerning its contribution to maintenance activities and consequently to the knowledge creation process.

Furthermore, the research showed the relative lack of the experiential knowledge asset of trust in the reactive maintenance branch of the combination stage. Thus, in some cases, middle management prevent lower management from using sources of explicit knowledge. In other cases, engineers refrain from acting as merchants of foresight for the enhancement of knowledge assets, which contain knowledge of questionable quality, for their use in planning and scheduling, despite their apparent understanding of the assets' potential role.

The lack of merchants of foresight is also evident in the case of the PD, since the merchants could promote a new system in which the PD would have an enhanced role, and other participants in systemizing Ba would recognize its "intention to act" (Nonaka 1994) as connector of knowledge creation initiatives. The merchants of foresight would also improve unequal treatment and access to some explicit knowledge sources and would help the organization overcome past experiences concerning drawbacks in the use of ICT, such as the failed attempts in preparing a maintenance schedule. This is necessary because, with the existing situation at the MD, both ICT and databases very often fail to support knowledge justification even in cases of quite common equipment repairs, since there is limited utilization or application of their contained knowledge. Moreover, the merchants of foresight would facilitate the process for the building of trust and commitment both in the skills of the PD and in the potential ability of ICT to support the combination stage. Indicatively they could promote standardisation in the creation of JPs, through the emphasis on standardising repair methods, which would also fortify the organizational aspect of the engineering culture for safety. Consequently, this would enhance the role of the CMMS, both in the management and the dissemination of this systemic knowledge asset. However, the standardized use of ICT would also need the preparation of a JP Database and would require the resolution of other issues that have to do with the lack of explicit knowledge sources, and power struggles related to its management.

Besides databases and ICT, a central planning and scheduling system, which would allow the evaluation and extraction of knowledge from standardised systemic knowledge assets by a non-active participant in various types of Ba, such as the PD, would require the removal of barriers set by the existing status quo. According to the established situation, both in preventive and reactive maintenance, frequently knowledge assets are built within departmental boundaries by those who can play the role of the knowledge catalyst and the role of the connector of knowledge initiatives. Such people, who not only can create systemizing Ba by collecting explicit knowledge, but can also synthesize and integrate this knowledge, are in the position to exploit up-to-date information flows and are usually active players in the organizational routine of the job execution. A change in the planning system would also require the withdrawal of the negative experiential knowledge assets of mistrust and low care demonstrated towards the PD by both middle and lower management, when it comes to the abolishment of the roles of the knowledge catalyst and the connector of knowledge initiatives by their departments.

A merchant of foresight within the MD should also provide clear-cut directions and take some action in a dual way. First, they should promote the creation of non-existent knowledge sources, such as a database with the maintenance strategies. Second in cases in which personnel neglects already existing internal and external explicit knowledge sources they should promote their use and maintenance. For example, the SED have not developed an understanding on how to take advantage of the reports produced by the Inspection Department. As a result they do not synthesize the reports' knowledge any further.

7.3.4 Internalization, exercizing Ba and routine knowledge assets

The final stage of the SECI process within the maintenance case organization is identified with the acquisition of real world knowledge (Nonaka et al. 1994) by personnel through the numerous opportunities for the execution of corrective and preventive maintenance works within the venues of the technologically advanced refinery A. At this stage the crystallized repair concept is exposed and compared to the reality of the world as personnel practice maintenance techniques during job execution.

The investigation contributes to theoretical debates by showing that not only does this internalization process trigger the second stage of knowledge justification, which is the justification in action, but also creates two kinds of maintenance knowledge. First, the process justifies the repair concept itself, producing knowledge in the form of technical maintenance know-how, working practices and new maintenance specifications. However, this justification cannot, and should not, be seen independently from the justification (or the rejection) of the process that was followed from the acquisition of maintenance skills and the initiation of the maintenance work until its completion. At a higher level this creates a kind of knowledge that pertains to the process of organizing maintenance work, or in other words, to maintenance management knowledge concerning the organizational capacity for action (Stehr 1992). Hence, such kind of management knowledge can change, for example, the routine knowledge assets of the skill acquisition process at the socialization stage, the fault identification process at the externalization stage, and the planning and scheduling function at the combination stage. The knowledge justification process also gradually shapes personnel's maintenance culture. From this perspective, the research showed that the development of a proactive maintenance approach in the ED and the ID is actually the result of this knowledge creation process, which has led incrementally to the competitive advantage of cost effective and more organized maintenance.

Even in cases in which the repair concept fails to become justified, this nevertheless contributes to the creation of new knowledge, since personnel enrich their tacit knowledge base by acquiring the experience that something in the refinery cannot be done in that particular way. Usually reactive repair concepts formulated under strict time constraints and in a sense of crisis (Nonaka 1988a; 1994; Senge 1990b; Leonard 1998) are often bound to turn out to be incorrect and become rejected. However, and as the case of the SED indicated, knowledge from wrong fault identification becomes part of the accumulated stock of know-how influencing future repairs (Cohen and Bacdayan 1994; Nelson and Winter 1982). Such knowledge often acts as a conformance mechanism that reinforces the already existing organizational capacity for action.

However, the internalization stage does not always result in the creation of new knowledge either with the justification or the rejection of the repair concept, and the process through which this has been developed. In circumstances where the repair concept does not contain any elements of innovative and creative thinking, such as in routine and repetitive works, the execution of the repair contributes to the re-justification of older knowledge. This sustains previously created organizational know-how (Dreyfus and Dreyfus, 1986) and certain patterns of thinking, action and interaction.

In the final stage of maintenance, the repair takes place in many small tasks, undertaken by autonomous teams. This process is nothing other than the beginning of the actualisation in action and practice of the systemic knowledge asset of the JP, which guides knowledge internalization. The compliance, to a certain extent, of the work execution with this knowledge asset can be attributed to the basic trait of the engineering culture (Schein 1996): the focus on safety within the industrial environment of the case organization. Lower management, through the performance of the role of the connector of knowledge initiatives, usually cover the numerous information gaps within this knowledge asset.

Similar to the previous stages of the SECI process, the routinization and embeddedness of the explicit knowledge of the JP into routine knowledge assets, as the organization carries out its daily business, occurs based on a routine knowledge asset that pertains to job execution. The two branches of this knowledge asset - preventive and reactive - contribute to the conversion of explicit knowledge into tacit knowledge with the parallel development of fundamentally different maintenance approaches and subcultures (Smircich 1983; Van Maanen 1991; Rosen

1991; Trice and Beyer 1992). These approaches to maintenance skills, routines and culture range widely, from the adoption of a totally preventative to a totally reactive perspective.

Both proactive and reactive maintenance job execution routines within the refinery are largely tacit (Nelson and Winter 1982) and flexible, enabling practical action (Nonaka et al. 2001a; Stehr 1992). In addition, and due to the fact that the JP does not contain exact job instructions or concrete procedures, which could act as a mechanism for the reinforcement of routines, the internalisation process is not restricted simply to the memorization of maintenance tasks. Rather, the process involves the conscious enrichment of the employees' tacit database, since the execution experience provides the participants of exercising Ba with actual feedback that can verify, or reshape and transform their mental models about maintenance. The accumulation of tacit knowledge at the individual level can then set off a new spiral of knowledge creation through its sharing during socialization.

The exercising Ba interactions through which employees acquire their know-how and embody culture, when doing their daily business, put in motion the organizational maintenance job execution routines. However, these interactions vary greatly amongst the hierarchical levels and across the different departments. The PD personnel are not active participants in this type of Ba, since their involvement is limited to capturing information after the completion of the job. The lack of the systemic knowledge asset of the Personnel Database also deprives planners from assigning the JPs' tasks to personnel.

Thus, both in reactive and in proactive maintenance, the interactions of the multi-actor organizational routine (Cohen and Bacdayan 1994; Nelson and Winter 1982) for the execution of repairs are dominated by the performance of the roles of the knowledge catalyst and the connector of knowledge initiatives by lower management, as, for example, the case of the blocked pressure relief valves indicated. Hence, lower management connect the administrative with the executing microcommunities, while they create exercising Ba by selecting the microcommunity of the repair crew. Supervisors, in a demonstration of autonomous action and authority (Cohen and Bacdayan 1994), also manipulate information flows and knowledge (Davenport 1993), achieving coherence to overlapping maintenance tasks (Teece et al. 2000). Furthermore, in a role of knowledge catalyst, they move freely across boundaries coordinating crews simultaneously with the inspection of new faults, while they are assisted by simple virtual means such as wireless telephones and the technical drawings.

However, the supervisors' role also causes evident problems, since they regulate both the access to knowledge sources and the distribution of knowledge, while they control the participation in exercising Ba through the experiential knowledge asset of competence trust. This intervention, in combination with the lack of an official mechanism responsible for the collection, storage or distribution of newly created knowledge, sometimes limits the organization not only in spreading its knowledge, which usually remains within team or departmental boundaries, but also in making a more effective utilization of this knowledge, since often personnel forget it and go through its rediscovery process again.

Exercising Ba interactions differ significantly between reactive and proactive maintenance, especially when it comes to the role of middle management. Hence, and as the examples of the ED and the ID indicate, middle management "with enacting liaisoning" (Nonaka et al. 1994), and supported by a variety of virtual media and shared maps of cooperation, often in the form of documents and methodologies, act within exercising Ba mainly as knowledge catalysts, who facilitate the production of knowledge concerning the organization of maintenance repairs. Furthermore, by approving decisions and the repair outcome, they integrate and justify the knowledge produced by various microcommunities. In addition, in the ID and the ED, engineers demonstrate openly not only competence trust to lower management, but also real feelings of companionship, and this reflects the influence of the experiential knowledge asset of care (Von Krogh 1998).

The results of such quality interactions are evident in the creation of routine knowledge assets, since both the ED and the ID exhibit the systematic development of knowledge in the form of rather equally distributed preventive maintenance skills and routines, which are coupled with an associated culture. The gradual adoption of a preventive maintenance philosophy followed the development of an understanding about its value, since it reduces uncertainty by combining multiple information flows. This development was also assisted by personnel's high educational level, while it was also justified historically through experiential learning (Kolb 1984; Cohen and Bacdayan 1994).

Within the ED and the ID, problem solving enabled the improvement of preventive maintenance routines (Levitt and March 1988), while in addition experimentation and recombination of older routines had also an important contribution to their formation. Nevertheless, and since the routines had to laid a balance among conflicting interests, they did not cause radical and fundamental organizational innovation (Hedlung 1994). So, for example, routines integrated manufacturer's knowledge with local maintenance knowledge (Nelson and Winter 1982; Grant and Baden-Fuller 2000). A decisive factor in this development also appears to be the existence and the promotion by middle management of informal departmental maintenance policies, which act as a knowledge vision (Von Krogh et al. 2000a) that directs the activities in the ID and the ED. Such policies also contribute to the acquisition and the imitation (Nelson and Winter 1982) of preventive maintenance skills, even in cases where these skills are not firm-specific. Another decisive factor for this development is that exercising Ba interactions in the ID and the ED were also strongly supported by ICT.

Moreover, especially in the ED and the ID the establishment of preventive maintenance routines was followed by the creation of the routine knowledge asset of preventive culture. Such a culture, which is stimulated by the favourable condition of requisite variety, since personnel are frequently involved in projects with new technologies, fosters knowledge creation by impelling future departmental actions and learning. The research indicated the existence of important culture embedding, articulation and reinforcement mechanisms (Schein 1985). Thus, mechanisms such as the frequent use of measurement and control, role modelling, teaching and coaching, are coupled with practices for personnel allocation that enable the utilization of otherwise idle personnel. These mechanisms contribute to the embedding of a preventive maintenance philosophy counteracting other not so favourable conditions for the creation, articulation and reinforcement of a preventive maintenance culture, such as the existence of a non-standardised reward and promotions system, the existence of outdated organizational procedures, and the lack of formal statements about departmental and divisional philosophy (Schein 1985).

However, the development of proactive maintenance routines is not always accompanied by a preventive culture. The example of the RED demonstrated that the utilization of the shared map of cooperation of condition monitoring contributed to the development of preventive maintenance skills and multi-actor and tacit routines. Such routines are executed with the limited use of systemic knowledge assets and shared maps of cooperation, while lower management regulate information flows for the coordination of departmental actions (Davenport 1993; Teece et al. 2000).

Nevertheless, neglect of the acquisition of additional preventive maintenance skills than those already existing and of their integration within a holistic preventive maintenance scheme reflect failure in developing of a preventive maintenance culture. The research indicated that this could be attributed to a lack of provision by middle management of a knowledge vision, which would have directed personnel's intention to act. Moreover, within the RED some culture embedding, articulation and reinforcement mechanisms appear somewhat weakened. This becomes evident with the relative absence of explicit measures and controls, and the lack of formal policy statements, which deprive personnel from creating a common point of reference, which could be useful during the justification of knowledge.

On the other hand, the reactive maintenance branch of the routine knowledge asset of job execution contrasts significantly with the preventive maintenance branch. Hence, the SED example demonstrated a different knowledge creation mode with both the existence of espoused and historically justified (Cohen and Bacdayan 1994) reactive maintenance routines and culture. In this case, the contribution of the departmental project and business layers is also significant, since they do not stimulate personnel's actions and interactions. In addition the quality of interactions and the use of media within the SED, provides a contrast with departments that adopt preventive maintenance approach. Thus, very often, interactions between middle and lower management are characterised by relative distrust, which prevents the use of knowledge sources and enriched JPs for the execution of the job. Furthermore, the ICT support of these interactions is practically non-existent.

The research also revealed that the long-established departmental reactive maintenance routines and the departmental ability to act (Stehr 1992) are characterised by time pressure, which is often caused by top management's aim to ensure a safe and fast solution, but makes work quite unpleasant. Moreover, the routines at the SED have been shaped in conjunction with the adoption of reactive improvisational solutions (Moorman and Miner 1998). When these solutions are unsuccessful, a common practice suggests the discarding of equipment and its replacement, instead of its repair.

The SED's existing culture is maintained by the lack of culture articulation and reinforcement mechanisms, such as measures and controls (Schein 1985) for the assessment of technical work. This, in conjunction with a lack of concrete procedures, allows not only the inconsistent use of virtual media, but also inconsistent use of knowledge assets and information flows, contributing to the creation of an inconsistent reactive culture. The unofficial system for rewards promotes the continuation of this reactive maintenance approach, but not to a change in personnel's feelings that some tasks underestimate them.

The research also pointed out the lack of another very important culture articulation and reinforcement mechanism associated with the existing organization of Petrochem and the procedures for the initiation of maintenance work (Schein 1985). Hence, the SED is deprived of an important shared map of cooperation, since the Inspections Department makes exclusive use of the basic method for conducting preventive maintenance measurements. In addition, the limited interactions between the Inspections Department and the SED, which reflect the lack of knowledge catalyst and merchant of foresight roles for the creation of collaborative Ba and the provision of direction respectively, minimize opportunities for the adoption of a different approach.

Furthermore, the PD provides a special example of a reactive approach to maintenance work. Hence, despite a well-developed understanding of the value of preventive maintenance, the PD lacks the necessary resources, in the form of knowledge assets (such as maintenance skills, databases and ICT applications) to perform its function. This situation is also strongly influenced by a lack of a knowledge vision and top management's commitment.

The execution of reactive and proactive maintenance work promotes the acquisition of real world knowledge. Nevertheless, internalization is also connected to the acquisition of virtual world knowledge (Nonaka et al. 1994). The empirically created and non-standardised training programme, and especially those parts that are related to experimentation or learning by trial and error, are examples of such knowledge acquisition. Reflection and hands-on experience allow individuals to embody explicit knowledge through their involvement in the execution of jobs. This process also facilitates the creation of mental models about maintenance activities and enriches personnel's tacit knowledge base, since they understand not only the world of the refinery, but also themselves. Hence, personnel are able to draw certain conclusions "when a situation has a particular constellation" (Dreyfus and Dreyfus 1986). Skills and know-how acquired during the internalization stage can then be transferred to other colleagues during socialization through personal interactions. This is an indication of the continuity of the knowledge creation spiral.

Opportunities for the acquisition of virtual world knowledge are also provided through another form of training: attendance at seminars and conferences, mainly by middle management. This activity, which is strongly encouraged by top management's role as a merchant of foresight has, on many occasions, improved incrementally (Hedlung 1994) personnel's capacity to act in maintenance repairs by deviating from the systemic knowledge assets which take the form of manufacturer's instructions. In this way, personnel created new firm-specific knowledge.

Besides internalization in the form of training, very often both the reactive and the proactive branches of the routine knowledge asset of job execution are coupled with a branch that concerns experimentation and simulation. When job execution includes this branch the personnel have additional opportunities to internalize virtual world knowledge. The research showed that internalization in the form of experimentation and simulation can either have a systematic or an emergent, unplanned, improvisational and non-standardised character (Leonard 1998). In the latter case, management frequently recognise the spontaneously formed Ba, and allow the acquisition of virtual world knowledge through learning by doing in the form of "trial-and-error" of repeated tests. Evidence indicates that this kind of internalization usually has temporary results. However, in some cases, more permanent solutions that started as experiments became part of the everyday working practice and created know-how for daily operations of the refinery. Lower management had also a decisive influence upon the application and the dissemination of this type of knowledge.

Experimentation is not always successful, while often its emergent nature, which is reflected in the spontaneous modification of procedures and equipment, contributes to the obstruction of the establishment of central coordination – in other words the performance of the role of connector of knowledge initiatives - by the PD.

However, experimentation is promoted by requisite variety enhancing activities, such as the construction projects and the operation of the refinery units. These activities allow the embodiment of new technical know-how and enrich personnel's tacit knowledge with the acquisition of experience. Experimentation with new (equipment) technologies that contribute to the acquisition of virtual world knowledge is often assisted by virtual media, such as simulation packages or other software applications (Thomke 2001).

In addition, when it comes to the interactions of the exercising Ba that underlie this virtual world knowledge acquisition, the investigation indicated the existence of rich and often harmonious interactions amongst middle and lower management. However, these interactions are usually limited within departmental boundaries, sometimes due to lack of interdepartmental trust, sometimes due to the lack of a concrete knowledge vision that restricts knowledge amplification. Hence, the case of simulations at the ID indicated that middle management, having been prompted by external equipment suppliers, acted as merchants of foresight both by introducing simulation packages and by directing trusted supervisors. Thus, lower management are encouraged to act as knowledge catalysts by performing simulations, and in doing so, they embody knowledge. Very often middle management also act as connectors of knowledge initiatives since they use simulation results for the synthesis of systemic knowledge assets, such as feasibility studies that are used for the justification of knowledge.

Furthermore, middle management's interpretation of top management's directives for increased safety resulted in the introduction of simulation exercises at the ED that increase requisite variety and prepare personnel for their roles. During these simulation exercises middle management act as knowledge catalysts by creating exercising Ba, by assigning roles to departmental personnel and by examining possible improvements.

In general, simulations are useful tools for knowledge catalysts, since they increase personnel's experience of equipment operation. Furthermore, they incrementally improve maintenance practices (Hedlung 1994) and result in the formation of systemic knowledge assets, such as databases. Information from simulations often dictates the preferable course of action, determining, the routine knowledge asset of the job execution that needs to be followed. The tool of simulations is used mainly by the ED and the ID – that is, those departments that practice preventive maintenance.

In experimentation, the trial-and-error character of which is considered as synonymous with maintenance within the MD, interactions are somehow different from simulations, since amongst other things, they mainly have an emergent nature (Leonard 1998). Thus, by acting as connectors of knowledge initiatives, lower management, besides planning and scheduling, encourage and approve departmental experimentations. In other cases, such as in the examples of the pressure relief valves and corroded pipes, supervisors regulated and controlled interactions by acting as knowledge catalysts, since they triggered the creation of technical know-how and adjustments to local operating needs. This was achieved by motivating crews to contribute to the solution of the problem and to experiment. Supervisors also helped personnel to internalize the newly created knowledge. In general, the research indicated that not only in case of virtual world knowledge acquisition, but also in cases of real world knowledge acquisition, lower management actively play the roles of knowledge catalysts and the connectors of knowledge initiatives.

7.4 Summary

This chapter has attempted to make sense of the knowledge creation process that emerged from the Petrochem case study. This was attempted by pursuing a range of themes. First, the analysis examined the role of the conditions of care, trust, commitment, autonomy, creative chaos, information redundancy and requisite variety and the role of a knowledge vision in giving form to and energizing of the knowledge creation process and its context. Then, the chapter, following the natural flow of maintenance works, explained the SECI process, as applied to the case. In this way, the chapter analysed the socialization process as a process that transfers and accumulates skills and other tacit knowledge, and as a collection of internal and external information. Afterwards, the externalization stage of knowledge creation was explained as a process in which maintenance personnel explicate their tacit knowledge, when they make use of their maintenance skills during the identification of faults for equipment repairs. The combination stage of knowledge creation was seen in the planning and scheduling function of the maintenance organization and was analyzed as a process that involves the acquisition, integration and processing of explicit knowledge for the synthesis and the dissemination of complex explicit knowledge sets. The chapter concludes with a theme that sees in the execution of maintenance works the internalization stage of knowledge creation in which personnel create and acquire new knowledge on technical issues and on the management and the organization of maintenance works, meaning the organizational capacity for action.

The explanation of the SECI process has explored in some way this concept in the context of the case organization and provided a useful lens for understanding the development of the knowledge creation process. However, the analysis of this chapter was not limited to the SECI process, since it pointed out interrelations of the process with its social and organizational context, and the knowledge assets involved.

The final chapter that follows reflects on the knowledge creation process and points out the contribution of the research.

8

Conclusions and Summary

8.1 Introduction

This research has attempted to make sense of knowledge creation as a social process and to explain its interrelationships, not only with the wider social and organizational context within which it unfolds, but also with its content, in a similar way to how Walsham (1993) addresses the issues of context and content in organizational change processes. The nature and the complexity of the process of knowledge creation required a review of literature from a wide range of research areas, such as knowledge management, organizational studies and research methodology for information systems, and the combined utilization of various concepts in order to analyse the data collected from this particular maintenance service work organization. In doing so, the thesis endeavoured to provide a holistic, processual view of knowledge creation. This concluding chapter summarizes the main arguments of the thesis, details the threefold methodological, theoretical and practical contribution of the research, points out some important limitations and provides some directions for the guidance of future work.

8.2 Overview of thesis

Chapter One introduced the research journey. First, it presented the general background, the initial motivation and the significance of the research. Then, it explained the aim and the investigative focus, which is to make sense of knowledge creation as a social process in a holistic manner. This objective was linked to two research questions: How knowledge creation processes interrelate with their social and organizational context and their content, and how these interrelationships are influenced by individual and group actions and interactions. The chapter explained that the research had a theoretical, practical and methodological contribution, and presented an overview of the thesis.

Chapter two presented the research framework adopted in order to pursue the investigation. It reviewed and critiqued literature from the fields of organizational studies, knowledge management, and knowledge processes in an attempt to position the research within the broader literature and to map associated debates, issues and research gaps. More specifically, amongst frameworks that deal with processes of knowledge creation and adopt a structuralist perspective (Spender 1996a, 1998; Blackler 1995; Nonaka 1994), the chapter depicted and described Nonaka's framework (Nonaka 1991; 1994; Nonaka and Takeuchi 1995) as being suitable to provide a holistic perspective of the process. This is so since the Unified Model of Dynamic Knowledge Creation (Nonaka et al. 2001a) not only explains how processes of knowledge creation develop, through the SECI process, but also interrelates them with their context and their content, through the concepts of Ba and knowledge assets. The chapter pointed out that little empirical research had been conducted in relation to the framework's three constituent elements, since these had previously been examined separately. It also added that the academic literature lacks holistic empirical studies that explain the association of the knowledge creation process with its content and context. The chapter went on to present a taxonomy of Ba through which the research approaches the context of the knowledge creation process. It also explained concern for the contribution of individual and group roles for the shaping of the social context, and introduced the knowledge activism framework (Von Krogh et al. 1997), which was utilized for their analysis. Moreover, the chapter explicated the thesis' concern about the contribution of the conditions of autonomy, creative chaos, information redundancy, requisite variety, care, trust and commitment to building and energizing the process context by influencing social interactions. The chapter also explained how the concept of knowledge assets was involved in the investigation, pointing out the issues of their development, utilization and management within the knowledge creation process. Finally, it was noted that the investigation would attempt to address aspects of the management of the knowledge creation processes within the case organization, to present the infrastructure that supports this social process, and to make sense of the role of the knowledge vision in providing direction.

Chapter three went more deeply into the underpinning philosophical and methodological assumptions of the investigation, described aspects of the research design and analysis, and suggested that an approach to inquiry, which is explanatory, case-based and interpretative, was appropriate for this research. It began by discussing key aspects of the investigative focus that influence both the research assumptions and the investigative approach (Robey 1996). As such, the chapter explicated the adopted definition of the term "process" (Van de Ven 1992) and described the nature of a process inquiry. It went on to argue that an interpretative philosophical and methodological approach (Chua 1986) rooted in phenomenology (Boland 1979; 1985) is in accordance with the investigative focus and the adopted definition of process. Furthermore, interpretivism is a suitable approach due to the role of the researcher that cannot assume a neutral stance (Orlikowski and Baroudi 1991) and due to the use of theory (Eisenhardt 1989) within the research, which is used both as a guide to data collection, but also as the primary lens through which collected data are interpreted (Orlikowski 1993; Walsham 1993; Eisenhardt 1989). Then, the chapter explained the reasons for the adoption of a case research strategy (Benbasat et al. 1987), which, amongst other things, include its ability to study knowledge creation processes within their natural setting (Benbasat et al. 1987; Luthans and Davis 1982) and the opportunity for the provision of a holistic view of processes (Gummesson 1991; Lincoln and Guba 2000). The chapter then dealt with the investigative approach, starting with the selection of the case organization and the negotiation that led to access being granted. Moreover, the interrelation of the role of the researcher, in the prior role of consultant, ensured both an increased access level and a certain level of preunderstanding of the local organizational and social setting (Gummesson 1991). The chapter then described the employment of multiple data collection methods and sampling strategies for the collection of a series of qualitative datasets that range from semi-structured interviews, documentation and archival records to direct and participant observation. Such an approach allowed the collection of a rich set of data surrounding the knowledge creation process and provided data source and methodological triangulation (Denzin 1978). The chapter described the establishment of rapport with case organization actors and detailed the data collection procedures and their principles (Yin 1984), which contributed to the reduction of common qualitative research biases (Miles and Huberman 1994; Klein and Myers 1999). In a subsequent theme the adopted data analysis strategy was explicated. This combined two general analytic strategies (Yin 1984; Arbnor and Bjerke 1997) that focused on the two research questions and the development of the case description. More specifically, the research adopted a particular type of pattern-matching strategy, an explanation-building mode of analysis, which also contained some elements of chronological analysis. Finally, and after a brief presentation of the unit of analysis, the chapter ended with some reflections on the quality of research conclusions, using Yin's (1984) criteria for case studies.

Chapter four introduced the case organization by presenting basic aspects of its business and project layers (Nonaka 1994; Ekstedt et al. 1999), such as its organizational structure and workload, within which the knowledge creation process unfolds. The description of the knowledge creation process business layer started with the provision of an overview and brief history of the case organization and continued with some indications of its quality, the educational profile of employees, and the training policy of the organization. Through the presentation of existing staffing procedures the chapter explained how this business layer is renewed. Then, the business layer description continued with a brief presentation of the venues of refinery A of Petrochem and in particular the non-flat hierarchies of the departments in the Maintenance Division. These are the main actors in the knowledge creation process examined in the thesis. The chapter went on to deal with one of the primary driving forces of the knowledge creation process - the maintenance workload - and explained its two fundamentally different aspects: proactive and reactive. Finally, the chapter focused on two aspects of the organizational knowledge base that assisted the development of an understanding of the knowledge creation process in maintenance. In so doing, the chapter described elements of the maintenance-related software applications, the CMMS and the CWMS, pointing out that they fail to create an organizational information network. The chapter concluded by delineating some important cultural elements and culture embedding, articulation and reinforcement mechanisms (Schein 1985) within Petrochem and the MD.

Chapter five described aspects of the conditions and knowledge vision in the MD that stimulate and direct individual and group actions and interactions within a knowledge creation process. It demonstrated reasons that commit individuals into this social process and presented aspects of the care and trust relationships in the MD. The chapter described some opportunities for autonomous action and paid particular attention to the operation of autonomous and self-organizing teams. The condition of creative chaos that stimulates interactions through the creation of a sense of crisis was also presented in a separate theme. Furthermore, the chapter focused on how the organization achieves information redundancy and requisite variety, leading contributions to organizational coherence and adaptation to environmental changes. The chapter concluded with a description of the existing equivocal and ambiguous vision that directs knowledge creation.

Chapter six narrated the story of maintenance service work in the MD through a knowledge creation perspective. Descriptions enriched with context-specific information accompanied the narration of episodes of the everyday maintenance working life, while emphasis was given to the roles of middle and lower management employees. Thus, the chapter presented the acquisition of maintenance skills, the transfer of information, the collection of information both from within and outside the MD, and focused on the deliberate or spontaneous interactions that facilitate these processes. The chapter also linked these interactions with the experiential knowledge assets of care, trust and improvisation. In addition, the chapter showed how maintenance personnel explicate their tacit knowledge when they use acquired skills and know-how in the fault identification process for building preventive and reactive maintenance repair concepts. Following the natural flow of works within the maintenance case organization, the narration drew attention to the planning and scheduling process of maintenance works through a description of the maintenance Job Plan. Finally, the chapter described the execution of maintenance repair based on the Job Plan and showed that this is frequently coupled with experimentation and simulation.

Chapter seven made sense of the data and empirical findings based on the theoretical framework that combined Nonaka's Unified Model of Dynamic Knowledge Creation with taxonomies and frameworks from the literature that delineate important roles for knowledge creation (Von Krogh et al. 1997) and episodes of the knowledge creation process (Nonaka et al. 1994). The analysis of maintenance work, which points out interrelationships between the knowledge creation process, with its context and its associated knowledge assets, contributes not only explanations, insights and specific conclusions about the knowledge creation process and its management, but also suggests ideas for conceptual developments and insights into the theoretical framework.

The interpretation commenced with a group of themes that focus on conditions that vitalize, energize and give quality to the knowledge creation process and to its context, and bind participants in it. The chapter proceeded with an analysis of the four stages of the SECI process as these are identified in the natural flow of maintenance work. Hence, initially the skill acquisition process and the situations that allow personnel to gather contextual and other information were analyzed through the prism of the socialization process that enables the transfer and the accumulation of tacit knowledge and the collection of internal and external information. The chapter then analyzed the fault identification process as the externalization stage of knowledge creation in which maintenance personnel explicate their tacit knowledge for equipment repairs. The planning and scheduling function of the maintenance organization was viewed as corresponding to the combination stage of knowledge creation, since it involves the acquisition, integration and processing of explicit knowledge for the synthesis and dissemination of explicit knowledge complexions. The execution of maintenance works was seen as the final –internalization - stage of the knowledge creation process in which personnel create and acquire new knowledge on technical maintenance issues and on the management and organization of maintenance work, in other words on the organizational capacity for action. Concurrent with analysis of the knowledge conversion stages of the knowledge creation process emphasis was given to the influence of the process context and the knowledge assets involved. The discussion of the knowledge creation process indicated its context-specific nature and pointed out the coexistence of different modes of this process. Their differences often depend on how and who participates in the process and reflect the context of the knowledge creation process as acting simultaneously as a platform for the sharing, integration, and utilization of knowledge.

8.3 Core contribution - a process view of knowledge creation

The process view of knowledge creation and the process's interrelation with its social and organizational context and content are addressed in a number of different ways. First, they are addressed through the adopted process inquiry and the associated research design, which is an important **methodological contribution**. The findings derived by the methodological approach to the investigative focus contribute to the body of knowledge with theoretical and practical implications. This thesis makes a contribution to interpretative research methodology by demonstrating the utility of an explanatory, case-based and interpretative approach to the holistic inquiry of the social process of knowledge creation. The research, which is based on the assumption that in order to understand and explain organizational knowledge and its creation process there is value in investigating knowledge work, is one of only a relatively few empirical studies that adopt an appropriate framework for making sense of the knowledge creation process within work organization. Through the theoretical lens of the Unified Model of Dynamic Knowledge Creation the research not only guides data collection, but also data analysis. Nonaka's framework suggests an approach to the investigative focus of the research through the SECI process that explains how knowledge creation unfolds, through the concept of Ba, which represents the process context, and through the concept of knowledge assets, which corresponds to the process content.

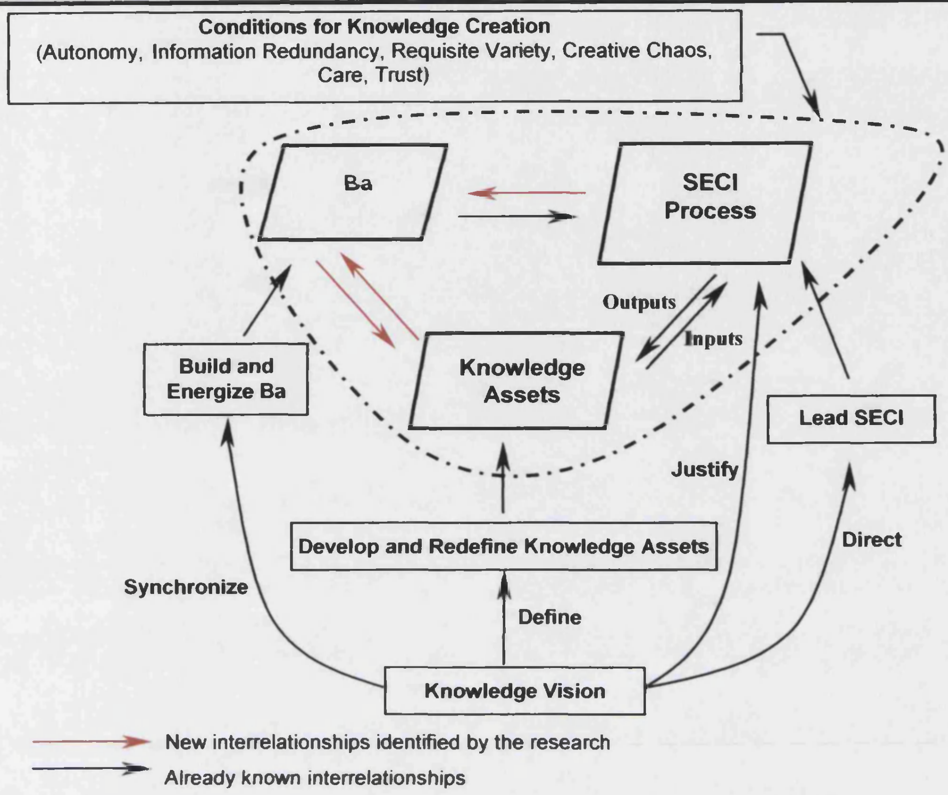
However, while Nonaka's framework acknowledges the importance of the social context for knowledge creation, it is incapable of capturing social interaction. The research points out the need to extend Nonaka's Unified Model of Dynamic Knowledge Creation by focusing on social actions and interactions of individuals and groups. In this respect this need was facilitated with the introduction and the complementary and supportive use of the knowledge activism framework (Von Krogh et al. 1997), a framework that describes knowledge-creating roles. However, this thesis does not simply repeat Von Krogh's (Von Krogh et al. 2000a) argument to focus on factors that enable knowledge creation. The research demonstrates that the delineation of social interactions with Von Krogh's knowledge enabling roles acts as a connecting element for the concept of the SECI process, the concept of Ba, and the concept of knowledge assets explaining of interrelations between them. This assists in capturing the process dimension of knowledge creation. Thus, the theoretical triangulation (Denzin 1978), achieved with the adoption of such a combined framework as an analytical tool within the case organization, is also a significant methodological contribution of the present study.

The insightful use of the combined framework in the present thesis not only assists the explanation of the complex and situated knowledge creation process with insights, but also assists in proposing ideas and suggestions for the extension of the adopted research framework and its related concepts, achieving a multilevel **theoretical contribution**.

The research looked for knowledge-creating action and interaction in the analysis of the natural flow of maintenance works within the case organization, based on the knowledge creation episodes, as identified by Nonaka et al. (1994), in each stage of the SECI process. Hence, it explained how the transfer and accumulation of time- and space- specific tacit knowledge, mainly in the form of the experiential knowledge assets of skills, know-how and mental models, and how the collection of internal and external information is involved in the socialization stage of knowledge creation. The research also showed how tacit knowledge is explicated during externalization. Moreover, the thesis demonstrated how explicit knowledge is acquired, integrated and processed for the synthesis and dissemination of complex knowledge sets at the combination stage. In the final stage of the knowledge creation process, the internalization stage, the inquiry explained the creation and acquisition of new knowledge by personnel through the justification in practice of the previously created knowledge sets. This approach can also be seen as a simple test of the knowledge creating episodes (Nonaka et al. 1994) within the context of the case organization.

The use of a combined framework moves us one step forward by explaining the continuity of the knowledge creation process, since it shows how the four stages of the SECI process are interconnected through the continuous flow of information, the evolution of knowledge assets and the intentions, actions and interactions of those involved in the process. Hence, the managerial and technical experiences, skills and know-how acquired at the socialization stage are utilized to identify equipment faults within a framework that has been shaped by multiple and often contradictory inflows of information concerning the existing situation. The combination stage requires the synthesis of the knowledge about the equipment fault with other available knowledge for planning and scheduling the repair. Finally, maintenance knowledge is justified and created with the actual execution of the maintenance work. The provision of insights about the continuity of the knowledge creation process identifies two-way links within the SECI process and the involved knowledge assets, the knowledge assets and the concept of Ba, and finally between the Ba and the SECI process (see also Figure 8.1). Nonaka's framework silences the existence of some of these two-way links, as shown in Figure 2.8.

Figure 8.1 Interrelationships between the SECI process, Ba and Knowledge Assets



The identified interrelationships amongst the three concepts are further clarified, since the research framework adopted succeeds in capturing and explaining the multi-dimensional character of the knowledge creation process by showing that each one stage of the SECI process consists of a multi-actor and largely tacit organizational routine (Nelson and Winter 1982; Cohen and Bacdayan 1994). With respect to the case study, the skill and know-how acquisition process, the fault identification process, the planning and scheduling process and the job execution process occur according to an organizational routine, in other words a knowledge asset. The organizational routines provide an aspect of the integration of the knowledge creation process with its context and content. These routines consist of branches, which are shaped by social interaction, information flows and the existing knowledge assets, and are followed according to prevailing circumstances. Thus, the thesis showed within these routines the existence and the operation of at least two mutually exclusive branches for organizational action - a preventive and a reactive maintenance branch. Very often both the reactive and the proactive organizational routine incorporate a branch that pertains to experimentation and simulation. The research shows how the routine knowledge assets of each knowledge creation stage are linked to the routines of the preceding and subsequent stages of the process.

The identification and description of organizational routines within each stage of the knowledge creation process provide a basis for understanding another theoretical contribution, an explanation of the coexistence of many different modes of the knowledge creation process within the same organization. The research demonstrates that knowledge concerning reactive and proactive maintenance is created by extremely diverse knowledge creation modes that are also associated to different business and project layers. These modes reflect a wide range of interactions in terms of who and how one participates in various types of Ba. They also reflect variations in the use of media and ICT, but most importantly in the development of an understanding on how to acquire, exploit, synthesize and manage information flows. In this respect, an important contribution is the explanation that the organizational routine of proactive maintenance is a result of the maintenance knowledge creation process, which produced incrementally an effective way of operation in some departments of the case organization. Proactive maintenance, as a capacity for action, recognizes the importance of viewing and understanding the whole process from skill acquisition to job execution as an inseparable totality.

However, the theoretical contribution of the research is not limited to the process of knowledge creation alone. It also reaches to its social and organizational context, since it illustrates for example the contribution of the context in the interpretation of information, which is a link between the concept of Ba and the SECI process. Moreover, the research demonstrates the usefulness of the concept of knowledge activism (Von Krogh et al. 1997) in process research by explaining how social interactions shape the social context of the process. Three distinctive roles that contribute to the definition of the context of the knowledge creation process are identified within the multi-actor organizational routines that regulate each stage of the knowledge creation process. The merchant of foresight provides direction to the process. The knowledge catalyst triggers the knowledge creation, initiates discussion and reflection, and creates space for social interaction. The role of the connector of knowledge initiatives links individuals and groups, thereby creating channels for the integration and dissemination of knowledge, often with the use of appropriate tools. This role, as the example of the ID Crew Coordinator indicated, often covers for the information weaknesses of the knowledge assets.

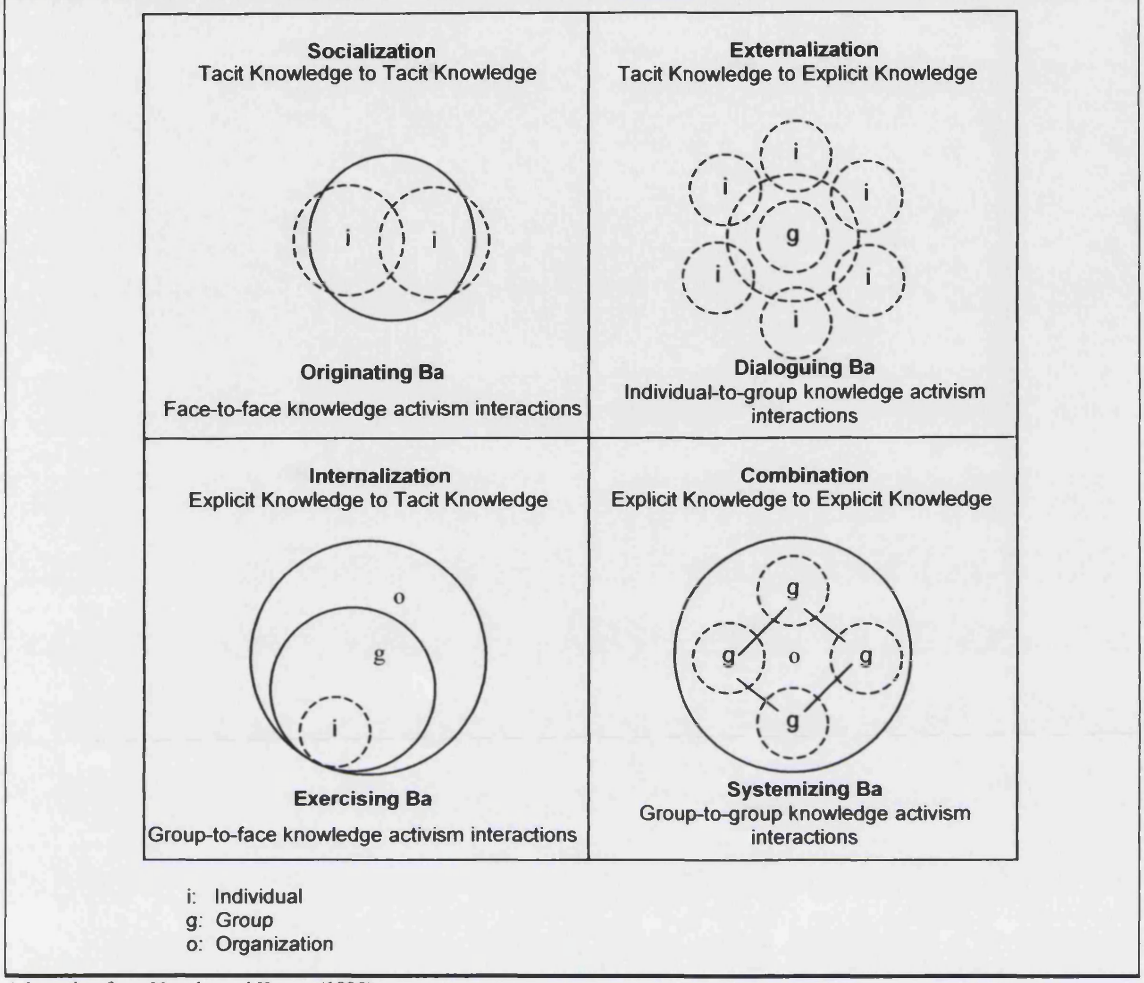
Nevertheless, my research extends Von Krogh's framework by questioning the idea that the knowledge activist roles are not always performed by the same person within the knowledge creation process. More specifically, the thesis explains that these roles can be performed by different individuals and groups, either synergistically or in a counterbalancing way. In doing so, the investigation also shows that these roles do not always facilitate the knowledge creation process.

Thus, my research explained how various management levels, and mainly middle and lower managers, perform knowledge activist roles for the direction of knowledge creation, the creation and the provision of actual, virtual or mental space for interaction, and the facilitation of the development and management of knowledge assets, either consciously or unconsciously. The synergistic action and interaction of both middle and lower management assists the creation and regulation of Ba, the collection of information, the accumulation and transferring of tacit and explicit knowledge (relationship of Ba with the SECI process), the building and the utilization of knowledge assets (relationship of Ba with knowledge assets) and the effective direction of knowledge creation.

The utilization of the knowledge activism framework and its application for the explanation of the actions and interactions of different management levels within the case organization provide insights into how the concept of knowledge activism contributes to the shaping of Ba. Hence, and as Figure 8.2 illustrates, knowledge activism interactions could be divided into four categories corresponding to each type of Ba. In the socialization stage, originating Ba is defined by face-to-face knowledge activism interactions, while, in the externalization stage, dialoguing Ba is shaped by interactions that connect the individual to larger teams or groups. In the combination stage, knowledge activism concerns interactions between groups, while in the final stage of the SECI process, the internalization stage, knowledge activism interactions allow individuals to enrich their tacit knowledge base in exercising Ba.

Furthermore, and besides approaching the social context through the knowledge activist roles, the research provides an explanation of how some organizational conditions and the knowledge vision energize and stimulate the knowledge activist roles and human interactions in general. For example, the research explained that the autonomous action and interaction of individuals and groups allow the framing of problems, very often through innovative thinking. This is an important prerequisite in the knowledge creation process. Furthermore, the research indicated that the beneficial creation of a sense of crisis in human interactions requires intrinsic energizing.

Figure 8.2 **Knowledge activism and Ba**



Adaptation from Nonaka and Konno (1998).

The empirical evidence that this research offers, represents another theoretical contribution in relation to the content of the knowledge creation process. This contribution pertains not only to an explanation of the development process of knowledge assets, but also to the demonstration of their connection and their role within each stage of the knowledge creation process. For example, the research demonstrates that the conceptual knowledge asset of the WO is often incapable of assisting the needs of the knowledge creation process, since it is rather static. The investigation shows how knowledge assets are the inputs, outputs and moderators of the knowledge creation process and demonstrates the continuity of this process through their continuous evolution. Thus, for example, maintenance skills create repair concepts, which are synthesized into job plans that are executed to reinforce maintenance routines. The thesis argues that each stage of the knowledge creation process cannot be seen independently from its interrelated knowledge assets. Hence, the research does not examine knowledge assets in isolation, since it not only shows the importance of individuals and groups in their creation, maintenance and utilization, but also explains the influence of tacit and explicit knowledge sources upon them. An important theoretical contribution of the research has to do with the explanation of the moderating influence of knowledge assets in the knowledge creation process, a relationship which is not very well explained by Nonaka's framework (see also Figure 2.8). Hence, knowledge assets can moderate the knowledge creation process, either by moderating social interaction, or by failing to assist information flows to the SECI process. For example, the empirical evidence indicates that knowledge assets, such as trust, influence social interaction, regulate participation in Ba and often reinforce boundaries, which usually concur with the actual functional and divisional boundaries of the organization. With the moderating influence of knowledge assets very often the social context for knowledge creation acquires the characteristic of the rather permanent membership, which is a property of communities of practice (Lave and Wegner 1991).

The research also showed that interactions amongst knowledge assets can be complementary or counterbalancing. For example, existing knowledge assets can prevent the creation of new assets. In contrast, the synergistic interaction of trust and care facilitates participation in Ba.

8.4 Other methodological, theoretical and practical contributions

In addition to the core contributions of the thesis relating to a process view of knowledge creation, the research has also a number of other methodological, theoretical and practical contributions. A secondary methodological contribution lies in the fact that my research recognizes the need to make sense of the intangible knowledge assets within the knowledge creation process and its socialization stage. Hence, theoretical triangulation is attempted, with the use of frameworks for the explanation of trust (Newell et al. 2002), care (Von Krogh 1998) and the stages of socialization (Feldman 1976; 1981), and improvisation (Moorman and Miner 1998). At this point, it should be emphasized that both the adopted frameworks for trust (Newell et al. 2002) and care (Von Krogh 1998) not only allow association with Nonaka's framework, but also the drawing of links between them, increasing the potential for a more holistic explanation of the knowledge creation process.

Additionally, and besides the methodological contribution that has to do with the adoption and utilization of the research framework, my thesis demonstrates how aspects of interpretative methods might be emphasized to accomplish research on knowledge processes. For example, the methodological contribution includes data source and methodological triangulation (Denzin 1978; Miles and Huberman 1994; Taylor and Bogdan 1998), which was attained through the adoption of multiple data collection methods for the production of various datasets. The employment of such an approach, along with detailing the procedures for the collection and the analysis of data, has a dual purpose. It demonstrates the authenticity of the results, while also reinforcing the overall quality of the research. Moreover, the inclusion of rich descriptions and interview quotes enables the reader to make sense of the research data on their own, enabling comparison with my interpretation of the process. In any case, my intention is to demonstrate my prolonged presence in the case organization and how this has borne fruit in terms of the investigation.

Another contribution of a theoretical kind, which can also be seen as an indication of the continuity of the knowledge creation process, concerns the fact that my research provides a basis for considering the identification of two stages of knowledge justification within the knowledge creation process. The first knowledge justification stage occurs during externalization, when individuals justify in reflection the knowledge they are about to bring to the real world. Thus, this justification in reflection explains why the externalization stage of knowledge creation is a reciprocal process of concept creation and rejection, since it requires the reduction of uncertainty through the exclusion of options that do not fulfil certain criteria. Later, during the internalization stage, knowledge is justified in action through its exposure to real world.

Another contribution concerns the explanation that the knowledge creation process justifies concurrently two kinds of knowledge. First, and with respect to the case study, the process justifies the knowledge object per se, meaning the technical knowledge for the maintenance repair. This kind of knowledge justification verifies (or sometimes rejects) the management and organization adopted for the execution of this maintenance work. At a higher level, the knowledge creation process also justifies the organizational capacity for action. This kind of knowledge either maintains or re-shapes the organizational routines of the SECI process.

Furthermore, the inquiry also delineates the socialization stage in terms of various phases and provides an explanation of their contribution to the knowledge creation process. Thus, for example, these phases facilitate the establishment of communication channels and the building of various types of trust and other knowledge assets.

An additional theoretical contribution concerning the concept of knowledge assets, and especially the intangible experiential knowledge assets, is the idea of their distinction into positive and negative assets. Such a distinction could provide a potential explanation for their moderating influence on the knowledge creation process.

In addition to the theoretical dimension, the research also has a practical contribution, mainly through the provision of insights and specific conclusions about the knowledge creation process and its management in the case company. Practical implications range from the influence of the workload on knowledge creation to the impact of various management levels on the social interactions of this process. These practical implications are important especially in cases where knowledge creation emerges somehow unconsciously through the daily activities of participants rather than in circumstances in which management is trying consciously to direct the creation, capturing and utilization of knowledge. With respect to the case study, my thesis demonstrates a situation in which there is not a deliberate and integrated facilitation of all four modes of the SECI process, despite the fact that in some instances there is partial deliberate building of Ba, with the provision of physical, cyber, or mental space.

The practical implications of the research should not neglect the relevance of the thesis to other settings. The findings of this investigation can be extrapolated not only to other maintenance service work organizations, but also other project-based organizations. Nevertheless, caution is required for the identification of organizational, social and infrastructure differences between the case organization and the organization in which the results might be transferred.

A secondary practical contribution of the research concerns the fact that it addresses the importance of the organizational structure and the project layer within which knowledge creation unfolds (Nonaka 1994; Ekstedt et al. 1999). Hence, the research showed the impact of organizational structure on individual autonomy, motivation, and commitment, and on the flow of information. Adaptations of the business layer are necessary for the improved performance of the knowledge activist roles, accommodating the needs of the project layer (Nonaka 1994) - the workload in other words. Such adaptations promote the condition of requisite variety and ensure the acquisition of new knowledge and skills, since they assist the elimination of boundaries for information flows.

In addition, the thesis provides a basis for considering the workload of each professional maintenance service organization, and potentially of any project-based organization, as an important driver of the knowledge creation process. Thus, with respect to the case study, the workload is conducive to the formation of different modes of the knowledge creation process. This is understood by the existence of a direct link between the project layer and knowledge assets, since, for example, the research explained that often the workload does not always justify the development and use of certain knowledge assets, such as in the case of the conceptual knowledge asset of the WO.

The research also contributes practical guidance by showing that active participation in the knowledge creation process requires at least an advanced beginner stage of skill competence (Dreyfus and Dreyfus 1986) from involved individuals. This specific conclusion, in combination with the indication that the individuals' participation in the originating Ba of socialization is required for the acquisition of these skills and the building of communication channels, can be used for the establishment of training, apprenticeship and mentoring programmes that will boost knowledge creation.

Another practical contribution concerns the fact that within the case organization, where little deliberate management of the knowledge creation process takes place, lower management are actively involved as knowledge catalysts and as connectors of knowledge initiatives in every mode of the knowledge creation process. Therefore, they control and regulate social interactions, the skill acquisition and trust building process, and the collection and transfer of information. Moreover, they often influence commitment and facilitate the creation, distribution and utilization of knowledge assets. Knowledge catalysts from lower management are very good at identifying and framing problems and at providing clear directions for action, and in doing so they increase possibilities for the creation of valuable technical knowledge. However, and while their guidance in the knowledge creation process achieves the resolution of many practical problems, it sometimes lacks a broader long-term vision, obstructing the enhancement of organizational capacity for action.

The findings on the role of lower management acquire practical value when they are viewed in conjunction with the role of middle management, which varies significantly across the preventive and reactive modes of the knowledge creation process. Hence, the research emphasizes the need to consider whether middle and lower management perform knowledge activist roles in a complementary or in a counterbalancing way.

On the one hand, in preventive maintenance, the management of the knowledge creation process is more conscious, since middle management provide important direction and act synergistically with lower management. Evidence shows that important value-adding knowledge-creating initiatives were introduced and assisted by middle management. Not only do middle management's interpretations of the existing knowledge vision enhance the process content decisively and increase the organizational capacity for action, but they also complement lower management and achieve the successful creation and utilization of knowledge assets. In such cases communication is good and information flows within an environment shaped by care and trust. Conversely, in reactive maintenance, the contribution of middle management is not so decisive, since their roles are often opposed to the actions of lower management. In such cases lower management guide knowledge creation, albeit over a short-term horizon.

Besides implications in relation to the influence of various management levels upon knowledge creation, another practical contribution is the identification of symptoms of the knowledge creation process, either with the lack of or the failure in the performance of the knowledge activist roles. For example, the inability of the role of the knowledge catalyst to create Ba results in limited knowledge integration, a necessary function for the creation of knowledge assets. Elsewhere, the thesis explained that the relative failure of the role of the merchant of foresight results in neglect of important knowledge sources and in the underestimation of the role of the knowledge assets.

With respect to the case study, where the knowledge creation process emerges naturally, the failure of an individual or a group to perform a role results in its substitution by another, more competent group in a "power of knowledge" game. For example, the supervisors substitute the PD in performing the role of the connector of knowledge initiatives, since this role requires the acquisition of context specific knowledge. The research also suggests that a failure in the performance of knowledge activist roles can contribute to the creation and maintenance of boundaries that obstruct knowledge creation through the miscreation of Ba and its inability to connect into a greater Basho. Furthermore, the inability of one group to perform the roles of knowledge activism shapes accordingly the organizational capacity for action, which can change with the introduction or withdrawal of knowledge activists.

The empirical evidence collected also contributed to the identification of factors that cause problems in the performance of the knowledge activist roles. One is the lack or neglect of shared maps of cooperation, which are practical tools, such as methodologies for focusing conversations. This usually limits the available information channels and results in the degeneration of knowledge assets. Furthermore, shared maps of cooperation are necessary in order for knowledge catalysts to read the current situation and stimulate interactions intrinsically by setting objectives (Senge 1990b). The study demonstrates that, in the absence of shared maps of cooperation, the use of metaphor/analogy facilitates knowledge creation by allowing the construction of mental models and the integration of knowledge. However, even this mechanism sometimes fails, since language turns out to be a rather ineffective means of communication in this context, requiring action or demonstration rather than words.

Initiated also by the evident influence of existing knowledge assets, and in particular the experiential knowledge assets of trust and care in the performance of the knowledge activist roles, the research suggests the need for the adoption of a humanitarian type of management of this social process. Such a management style will have to focus on the interactions of the involved participants in the knowledge creation process.

Many other practical implications stem from the, often contradictory, influence of the conditions that energize, stimulate and regulate not only the knowledge activist roles, but also interactions within the knowledge creation process in general. A practical implication of the research is not only the explanation that social interactions are influenced by trust, but also the identification of job rotation as an extremely important process for the building of two types of trust. Hence, the research makes the distinction: companion trust, which is built through socialization interactions and personal friendships, and competence trust, which regulates participation in Ba, since it is used as a resource allocation criterion. Companion trust is a prerequisite for the creation of competence trust. The thesis associates these types of trust with the maintenance knowledge creation process by demonstrating their development process, their interrelation to other knowledge assets, and their moderating impact upon human interactions and information flows.

Furthermore, job rotation, coupled with apprenticeship and mentoring, is also an important way for the realization of information redundancy and requisite variety. Thus, job rotation facilitates the development of organizational integration and cohesion, the development of a common history between employees, the acquisition and overlapping of skills and know-how, and the establishment of communication channels. However, the research suggests that the realization of redundancy of information through this process has also some weaknesses, since it is time- and cost- consuming and can produce unequally skilled personnel.

Another practical implication concerns the identification of a number of important reasons that commit individuals within the knowledge creation process. The research showed that many value-adding knowledge creation initiatives stem from committed individuals, who also tend to share knowledge. Nevertheless, the research also indicated cases in which participants are committed to the knowledge creation process due to fear of possible consequences and this sometimes forces them to mitigate risks and settle for less. This occurs in particular due to the fact that the organization does not realize the condition of creative chaos adequately for the stimulation of interactions. The sense of crisis stemming from the "navy culture" of the OD achieves the solution of problems by causing breakdowns of routines, habits and cognitive frameworks (Weick 1988; 1993); however, MD management can exploit these situations only opportunistically. Hence, managers maintain a "just get it done" environment, which limits self-reflection and opportunities for the framing of problems and the channelling of conflicts into the creation and energizing of dialoguing Ba. Moreover, there is limited use of shared maps of cooperation, which might otherwise allow the setting of ambitious objectives based on the existing organizational reality.

The investigation also showed the importance of autonomous action and autonomy for experimentation and for the investigation of new ideas, which often lead the case organization to technological innovation. Autonomy increases the chances of framing problems through innovative thinking, and for the provision of innovative solutions. The research also surfaced barriers that have prevented the formation of cross-functional autonomous teams and a flatter business layer. In general, small autonomous teams with well-educated leaders (Elkjaer 2000) boost the knowledge creation process.

Another practical contribution of the research is the idea that an organization can utilize technological discontinuities (Tushman and Anderson 1986) as a stimulus to the knowledge creation process. Technological discontinuities facilitate the realization of requisite variety, promote the building of organizational combinative capabilities (Kogut and Zander 1992) and fortify a culture (Schein 1985) that embraces new and diverse developments (Nonaka et al. 2001a) and fosters creativity (Vicari and Triolo 2000).

The research also showed the contribution of the non-existence of an information network that would allow "equal access to information throughout the organization" (Nonaka et al. 2001), and which amongst other things could facilitate requisite variety. The case organization's isolated ICT applications fail to create a virtually flat organization (Brown and Duguid 2000), where knowledge transcends boundaries through formal channels and people have access to vital and up-to-date information. In addition, the problem of equal access to information is also connected to the existence of the knowledge asset of competence trust (Newell et al. 2002) that bars social interactions on equal terms.

Another practical implication concerns the need for a knowledge vision within the knowledge creation process, and a merchant of foresight for its interpretation. Moreover, the thesis shows how an equivocal vision assists embracing creativity and diversity for the creation of context-specific knowledge and difficult-to-imitate knowledge assets.

Besides the practical contributions concerning the organizational conditions that energize social interaction, another practical implication pertains to the influence of culture embedding mechanisms (Schein 1985) within the knowledge creation process, or more accurately to their relative absence, at least in cases of reactive maintenance. Such mechanisms include the existence of measures and controls, criteria for scarce resource allocation, role modelling, teaching and coaching, and criteria for promotions, rewards and status. The thesis also highlights the contribution of culture articulation and reinforcement mechanisms (Schein 1985), such as the existence of organization systems, procedures, stories and myths, and formal statements of organizational philosophy. For example, the frequent narration of stories concerning the inability of the PD to operate properly acts as a conformance mechanism (Levitt and March 1988; Szulanski 2000) contributing to the maintenance of organizational routines in which connectors of knowledge initiatives belong to the lower management level.

Another practical outcome concerns the impact of tacit and explicit knowledge sources on the knowledge creation. In particular, the research points out aspects concerning their creation, utilization, and even their negligence. Hence, when the knowledge creation process emerges naturally, the creation and maintenance of knowledge assets and knowledge sources, such as, for example, databases, depend strongly on their utilization. The knowledge creation process creates knowledge sources and knowledge assets, where these are needed. The investigation indicated that the development process of knowledge sources and assets follows the organizational routine that directs each knowledge creation stage. Moreover, the condition of these knowledge assets depends on their manager and their user. With respect to the case study, it is important that the manager of the knowledge asset acquires context specific knowledge concerning its utilization. Lower management, who have such context specific knowledge, are often both managers and users of knowledge sources and assets. Hence, they are able to control many of the stages of the knowledge creation process, often with the use of the experiential knowledge asset of improvisation.

The existence (or absence) of tacit and explicit knowledge sources, along with the development of an understanding of their use and the provision of adequate time for this, are responsible, to a certain extent, for the qualitative difference of the same knowledge asset within different branches of the knowledge creation process. For example, in reactive maintenance, the integration of information flows fails and this is reflected in the fact that with some repairs more than one conceptual knowledge asset is created and coexist. However, both in proactive and reactive maintenance, the systemic knowledge asset of the JP appears as a non-fully integrated set of explicit knowledge, due to a lack of a merchant of foresight for the promotion of its use in maintenance activities.

The research also explains the practical implications of the time dimension on the knowledge creation process. Time urgency, coupled with a just-get-it-done environment, diminishes the quality of social interaction obstructing, the accessing, articulation and integration of knowledge.

In conclusion, both practitioners and management could benefit from a reflection on the practical insights and specific conclusions provided by the thesis in order to take advantage of the potential benefits and create new knowledge in the form of applicable and valuable knowledge assets. Hence, for example, these insights and specific conclusions could assist the creation of job rotation for transferring skills to employees, or even organizational restructuring initiatives, which might introduce new positions that would facilitate knowledge creation.

8.6 Limitations of the thesis

At this point it should be acknowledged that my thesis is bounded by many limitations. In fact limitations within an inquiry start with the statement of its research questions. From this point onwards every choice that is made concerning the research design is a trade-off between the opportunity for the realization of the research objective and the associated limitations. While space precludes the inclusion of every possible limitation of my thesis, this section categorizes limitations into two groups.

The first concerns limitations that pertain to the philosophical and methodological assumptions of my thesis and the adopted research design. The purpose of the case study was to explain how the process of knowledge creation unfolds and how this process interrelates with its social and organizational context, and with its content. For this reason chapter three argued for the adoption of an interpretative stance, which has the opportunity to accommodate limitations set by the use of theory as a sensemaking lens and by the dual role of the researcher. Moreover, the processual nature of the phenomena to be studied can also be seen as a limitation, which suggests the adoption of an explanatory case research strategy.

In addition, both the selection of the case organization and obtaining access to it are issues associated with limitations. More specifically, any attempt to replicate this type of investigation would probably need to address obstacles in relation to the necessarily deep access in which participants would not only share work documents, but would also be willing to share their views on their everyday work life. Furthermore, the selected case organization limits the applicability of the conclusions to other maintenance organizations. While generalizations to other types of project-based organizations are not excluded, such attempts should be examined with caution.

Other limitations concern the employment of the data collection methods and sampling strategies. One of the most evident omissions of the case study is the absence of evidence concerning the views of low-level technicians. Their experience is captured only indirectly through the Cultural and Satisfaction Survey.

The utilization of Yin's (1984) criteria for the assessment of the quality of conclusions arising from case studies is an effort to recognize the limitations and minimize their influence on the thesis.

The second group of limitations concerns the adequacy of the adopted research framework. The attempted theoretical triangulation with the use of the knowledge activism framework aimed at covering the limitation of Nonaka's framework to delineate social interactions. Thus, and while the combined utilization of frameworks gives the opportunity for the provision of a more holistic view of knowledge creation, concurrently the adoption of many concepts exposes the research framework to much criticism, starting with the feasibility of adopting such a complex framework. Indicatively, I will mention the fact that the knowledge activism framework is not capable of capturing, through its knowledge activist roles, the plurality of social interactions within the knowledge creation process. On the other hand, any framework will limit interpretation to its component parts, thereby excluding factors that may have otherwise proved insightful.

8.7 On future inquiry

Future research might explore the ideas presented in this thesis as a whole. It is self-evident that this theme cannot include all the issues that presented themselves during the inquiry, therefore only an indicative selection of areas for future research is included.

First, other researchers might examine how processes of knowledge creation unfold in different social and organizational settings than the maintenance division of a petrochemical company. Since the research revealed the context specific nature of knowledge creation, it is understood that the development of this process in other types of organization, or even in project-based organizations which operate in a different social and technological environment, could be substantially different. Second, the inquiry indicated in many instances that the knowledge creation process is strongly interrelated with other knowledge processes (Alavi and Leidner 2001), such as knowledge transfer, and knowledge storage and retrieval. This is so, since Ba interactions act as a platform for the concurrent development of these processes. Hence, it might prove useful to examine in greater detail the influence of other knowledge processes, such as knowledge transfer - often in the form of organizational change programmes - on knowledge creation. For example, a knowledge creation perspective on corporate change initiatives could provide useful insights regarding the realization of benefits. Others might wish to conduct a thorough investigation of the role of various genres of communication and media (Yates and Orlikowski 1992) within the stages of the knowledge creation process, since this current research acknowledged their importance for the creation of Ba, and the flow of information. However, for practical reasons that had to do with the focus and length of the present thesis, their study was not included within the scope of this research. Moreover, it might prove useful to investigate in greater detail the link between knowledge creation and Weick's concept of sensemaking (Weick 1988; 1995), since these two social processes share many common elements, such as the construction of meaning, the interactions that produce mutual understanding and the ability of an individual to deal with surprise.

Then, the idea of distinguishing between knowledge justification in reflection that occurs during the externalization stage of knowledge creation, and justification in action that occurs in the end of the SECI process could also be further explored. Similarly, the idea of dividing experiential knowledge assets into positive and negative ones provides another potential area for future research due to its ability to explain how knowledge assets can moderate or even differentiate the knowledge creation process.

My thesis attempted to explain individual and group interactions within the knowledge creation process with the use of the knowledge activism framework. However, since the roles of individuals are the connecting element in the process, its context and its content within the present research, the framework cannot hope to capture all interactions within the knowledge creation process. Thus, other frameworks or approaches might incorporate more of these interactions within the knowledge creation process. Moreover, the knowledge activism framework fails to explain who is the knowledge producer. A possible answer to this question is that the knowledge producer could be someone who creates knowledge assets. This issue is indicative of the need to consider extending the knowledge activism framework in further studies.

Other ideas or issues that could inform future research include how individuals take advantage of various tacit and explicit knowledge sources within the knowledge creation process and the influence of power relationships, and other organizational conditions than those presented in my thesis, on this process. Finally, an attractive idea for further research concerns the thorough examination of the variations in the same knowledge asset at various stages of knowledge creation with the aim to explain further the contribution of process content within knowledge creation.

8.8 Concluding remarks

In conclusion, the main concern of my research was to advance knowledge processes in general and the process of knowledge creation in particular. Spurred on by the lack of empirical studies that provide a processual view of knowledge creation this thesis endeavoured to explain not only how this process unfolds, but also its interdependence with its social and organizational context, and with its content. The thesis undertook in-depth research that embraced these issues in a holistic manner within the same analytical framework. Hence, based on the assumption that in order to understand organizational knowledge and the process of its creation, there is value in understanding work, the research within a professional maintenance service organization adopted an interpretative stance and an explanatory case research strategy. Theory was used not only as a driver for data collection, but also as a lens for making sense of the social process of knowledge creation. In addition to methodological and theoretical discussions, which include extensions to the research framework, ideas for conceptual developments and rich insights into the nature of the process, this thesis also provided specific conclusions of practical import that may be beneficial for the management of knowledge creation processes. The research does not claim that it has covered the issue of the knowledge creation process fully, since it acknowledges a number of limitations. Nonetheless, it can become a point of reference for both academics and practitioners and for future studies that might attempt to explore or explain further the ideas, issues, and concepts raised in here.

Appendix One - The four stages of knowledge conversion at the maintenance division

Socialization From tacit to tacit	Managerial and Technical (Maintenance) Skill Acquisition
Tacit knowledge accumulation	Top Management (Maintenance Manager) gather information from the Executive Board and from Managers of other Divisions, share experiences with the Maintenance Department Heads and are engaged in dialogues with competitors from other local refineries and with international partners.
	Middle Management (Department Heads & Engineers) acquire managerial and maintenance skills, gather information in daily meetings with Maintenance Manager and in daily informal meetings with their supervisors. Department Heads & Engineers share experiences with their supervisors, with middle management from the other refinery divisions and with external contractors and equipment suppliers and engage in dialogues with competitors from other local refineries.
	Lower Management (Supervisors) acquire managerial and maintenance skills, gather information from departmental engineers and technicians, share experiences with lower management from the other refinery divisions and with external contractors and equipment suppliers.
	Technicians acquire maintenance skills, gather information from departmental supervisors, share experiences with team members, other maintenance supervisors and technicians and with technicians from external contractors.
Extra-firm social information collection (wandering outside)	Top Management engage in "wandering about", getting ideas for corporate strategy from social life, interaction with external experts (Professional Institutions, conferences, other industries).
	Middle Management engage in "wandering about", getting ideas for corporate strategy and management tactics from social life, interaction with external experts (Professional Institutions, conferences, other industries).
	Lower Management engage in "wandering about", getting ideas for equipment maintenance from social life, interaction with external experts (contractors and suppliers)
	Technicians engage in "wandering about", getting ideas about their trade from social life and interactions with external experts (contractors and suppliers)
Intra-firm social information collection (wandering inside)	Top Management find new strategies and market opportunities by wandering about inside the firm (Refinery B)
	Middle Management find new maintenance strategies and market opportunities by wandering about inside the firm (Refinery B)
	Lower Management find new maintenance techniques by wandering about inside the firm (Refinery B)
	Technicians find new maintenance techniques by wandering about inside the firm (Refinery B)
Transfer of tacit knowledge	Top Management create a work environment that allows the transfer of tacit knowledge to middle management concerning local operating environment and corporate strategy (Spontaneous originating Ba)
	Middle Management create a work environment that allows their colleagues (mainly other engineers) to understand the objectives and practices of departmental maintenance and maintenance management.

	Lower Management create a work environment that allows peers to understand the craftsmanship and expertise from practise and demonstrations by the senior technicians
	Technicians exchange tacit knowledge with other team members and understand craftsmanship and expertise from practice and demonstrations by supervisors and senior technicians.
Externalization **From tacit to explicit**	**Fault Identification, Creation of the Maintenance Repair Concept**
	Top Management facilitate dialogue with middle management, the use of "abductive thinking", the use of metaphors in dialogue for concept creation (maintenance repair), the involvement of personnel from other Divisions in maintenance projects.
	Middle Management facilitate dialogue with peers and lower management, the use of "abductive thinking", the use of metaphors in dialogue for concept creation (maintenance repair), the involvement of personnel from other Divisions in maintenance projects.
	Lower Management facilitate dialogue with their team members, the use of "abductive thinking", the use of metaphors in dialogue for concept creation (maintenance repairs), the involvement of personnel from other Divisions in maintenance projects.
	Technicians are involved in dialogues with other team members and use metaphors (and story telling) in concept creation.
Combination **From explicit to explicit**	**Maintenance Planning and Scheduling**
Acquisition and integration	Top Management is engaged in maintenance strategies and operations, assembling internal and external data (budgets) and forecasts financial performance
	Middle Management is engaged in planning maintenance strategies and operations, assembling internal and external technical and financial data. Often use of communication technologies and forecasting (of technical performance indicators)
	Lower Management is engaged in planning maintenance activities and operations. In some cases they assemble internal technical data requested by middle management. Often they provide information to the Planning Department
	Technicians are very often engaged in providing internal data for the Planning Department
Synthesis and processing	Top Management build up material by gathering management figures and/or technical information from throughout the company.
	Middle Management build and create manuals, documents and databases for products and services and built up material by gathering management figures and/or technical information from throughout the company.
	Lower Management create informal documents and blueprints for maintenance activities and in some cases builds up material by gathering technical information from throughout the department.
	Technicians create informal documents, blueprints and tables with technical information.
Dissemination	Top Management engage in the planning and implementation of presentations to transmit newly created concepts.
	Middle Management engage in the informal meetings to transmit newly created concepts. They also disseminate Job Plans to technicians.
	Lower Management engage in the informal meetings to transmit newly created concepts. They also disseminate Job Plans to technicians.

	Technicians attend presentations to transmit newly created concepts.
Internalization **From explicit to tacit**	**Maintenance Repair Execution**
Personal experience. **Real-world knowledge acquisition**	Top Management engage in "enactive liaisoning" activities with the executing maintenance departments, work on overlapping activities during maintenance works, search for and share new values and thoughts, and share and try to understand management visions and values through communications with fellow members of the organization.
	Middle Management engage in "enactive liaisoning" activities with the executing maintenance departments, work on overlapping activities during maintenance works, search for and share new values and thoughts, and share and try to understand top management visions and values through communications with fellow members of the organization.
	Lower Management engage in "enactive liaisoning" activities with the executing maintenance departments, work on overlapping activities during maintenance works, search for and share new values and thoughts, and share and try to understand management visions and values through communications with fellow members of the organization.
	Technicians engage in "enactive liaisoning" activities with the executing maintenance departments, search for and share new values and thoughts, and share and try to understand management visions and values through communications with fellow members of the organization.
Simulation and experimentation. **Virtual world knowledge acquisition**	Top Management facilitate prototyping by providing financial and other resources, facilitates internal benchmarking and the challenging spirit within the organization.
	Middle Management facilitate prototyping, internal benchmarking and creates chaos within the organization. Managers form teams to conduct experiments and test "patents" and share results either with the department, or with their team.
	Lower Management facilitate prototyping, and creates chaos the organization. Supervisors form informal teams experiment with repaired equipment, test self-made "patents" and share results with the department or the maintenance organization.
	Senior Technicians facilitate prototyping and participate in the teams that experiment with repaired equipment, test self-made "patents" and share results with the department or the maintenance organization

Based on Nonaka et al. (1994).

Appendix Two - The role of ICT to knowledge work and knowledge creation

ICT Package	Use for knowledge work activities	Use in the knowledge creation process
Word processor	Authoring of reports, memoranda and presentations. Searching for documents. For clerical activities of formatting, input of data, filing and retrieving text files	Creation of conceptual and systemic knowledge assets. (Externalization and Combination Stage)
Spreadsheet processor	Analysis, modelling, communication and presentation. Modelling and analysis. Formulate, model, analyse, and decide activities	Tacit knowledge accumulation and transfer (Socialization Stage) Virtual world knowledge acquisition through experimentation (Internalization Stage)
Communications package with email and fax	Communication and coordination. Monitoring and searching for information	Tacit knowledge accumulation and transfer (Socialization Stage) Creation of interaction Ba (Externalization Stage) and cyber Ba (Combination Stage)
Web browser for internet or intranet	Scanning for information. Monitoring for information. Searching for information.	Tacit knowledge accumulation and transfer (Socialization Stage)
Presentations package	Communications including activities that present results of knowledge work, persuade readers and listeners, and motivate to action	Tacit knowledge accumulation and transfer (Socialization Stage)
Database package to build and/or access internal databases	Scan, search, and monitor activities. Clerical activities of filing and retrieving data and formatting reports with retrieved data	Creation of systemic knowledge assets (Combination Stage)
Personal information management software	Knowledge work activities of planning, organizing, time management, and scheduling	Tacit knowledge accumulation and transfer (Socialization Stage)
Graphics package with charting, drawing, and graphics functions	Modelling of processes by flowcharting, drawing or sketching. Communication activities of presentation and persuading	Tacit knowledge accumulation and transfer (Socialization Stage) Creation of conceptual knowledge assets (Externalization Stage)
Coordination software that provides coordination and communication with groups	Knowledge work activities within a group of scanning, monitoring, searching, modelling, planning, organizing, scheduling, authoring, deciding and communicating.	Ba creation (Originating, Interacting, Cyber, Exercising) for all stages of the knowledge creation process.
Knowledge management software that provides a shared repository for project reports, analyses, problem and solution commentaries, and so forth.	Scanning, monitoring; search, model, and formulate activities. The knowledge management software allows these activities to locate experience and knowledge in the organization or group.	Tacit knowledge accumulation and transfer (Socialization Stage)
Scheduling and project management schedule	Planning, organizing and scheduling.	Breakdown of concepts (Combination Stage) Management of the condition of Creative Chaos

On-line analytical processing software for exploration of multidimensional databases	Scanning, monitoring, searching, and analyzing activities.	Acquisition, integration and synthesis of systemic knowledge assets (Combination Stage)
Desktop publishing software	Communicate activities and clerical activities of formatting outputs.	Acquisition, integration and synthesis of systemic knowledge assets (Combination Stage)

Adaptation from Davis and Nauman (1999: 350-351)

Appendix Three - Stories from refinery A

Story A: Building a substation network

The investigation identified an example of successful knowledge creation at Petrochem that indicates how the four modes of the SECI process interact continuously and dynamically. This is the example of the establishment of a substations network at Petrochem.

At the beginning of the 1980's the Electrical Department (ED) of the refinery was the smallest department of the MD. In 1985 the number of the employees increased substantially. New personnel spent approximately two years gaining valuable knowledge on the maintenance of basic electrical equipment as they exposed themselves to hands-on-experiences (socialization). The ambitious decision of the Executive Board of the company to increase the refining capacity in 1986 (creative chaos) enabled personnel of all levels to gain additional experience. The ED engineers participated in the design of the electrical systems of the new units, learned about state-of-the-art technology and exchanged experiences with equipment suppliers, manufacturers and contractors. The 1987 refinery revamp was also beneficial for lower-level maintenance personnel, since they had the opportunity to accumulate knowledge and share experiences during the construction and the operation of new electrical equipment.

In summer 1988 an accident at the Public Electricity Company caused the largest black-out in the history of Greece that sunk two thirds of the country in the dark for almost a day. The refinery was forced to stop its production since it was dependent on the electricity supply of the Public Electricity Company. This environmental fluctuation triggered the creation of a new concept, the establishment of a substation network, which was driven by the vision for the elimination of future production and safety problems caused by similar failures to the electricity supply. The accumulated tacit knowledge of refinery's middle management started to crystallize through repeated discussions at various meetings. The head of the ED explained that MD decided to establish a substation network in order to protect the new investment.

The combination mode of knowledge creation was triggered when the explicit decision of refinery management was converted into more complicated and systematic sets of explicit knowledge. Explicit knowledge was collected from inside the company by engineers in the form of technical information and from equipment manufacturers and was combined and processed to form specifications of the substations that would be established. The head of the ED explained that a German contractor, mainly due to the conception that German companies produce very reliable electrical equipment, was chosen to build the first three substations.

The dedicated team of the ED to the installation of new electrical equipment, the "New Installations Team", participated in the construction of the new units. The actual construction of the first substations was the internalisation mode of knowledge creation in which explicit knowledge was shared throughout the organization and converted into tacit knowledge by refinery personnel. The head of the ED explained in an interview that the refinery personnel supported the external contractor during the construction, in order to understand the new know-how with the aim to become competent in the operation of the substation. Engineers and technicians read documents and manuals about the operation of the substations and enriched their tacit knowledge base. The ED personnel were also trained in the maintenance of the substations. Employees tested their knowledge during the operational tests and experimented with new equipment, enabling the embodiment of explicit knowledge by triggering learning by doing. The department head said also that management was very satisfied by the results of the training programme as personnel very soon became familiar with the new technology and acquired the skills on site both to operate and maintain the substations.

Moreover, the knowledge creation process was not limited in the abovementioned first cycle of the SECI process. Just after the beginning of the normal operation of the three substations a new cycle of the SECI process began. The socialization stage of the second cycle included the accumulation of experiences of the electrical department personnel in the actual operation and maintenance of the newly established substations. This lasted for a period of approximately two years. Then the concept that the network should expand started to formulate. The ED head said:

> "The first three substations could cover only a small part of the refinery units. After a couple of years from the successful installation of the first substations we decided to expand the network."

The second combination mode included the collection and compilation of technical information from all over the refinery to form the specifications of the new generation of substations that would be established. The next project was undertaken by a new contractor, which provided substations with different technology. The decision to establish substations of different technology gave employees the opportunity to combine information and knowledge differently, and energized the enabling condition for knowledge creation of requisite variety.

In addition, the ED employed personnel with academic qualifications such as electrical engineers and technologists, who are graduates of polytechnic schools, and staffed autonomous teams along with senior personnel. These teams were empowered to undertake the project. The results of the project were satisfactory according to the head of the ED who said that they had no surprises. The second cycle of the SECI process closes, just like the first one, with the training of personnel in the operation and maintenance of the second generation of substations, the operational tests and the studying of manuals and other relevant documents that enabled the conversion of explicit knowledge into embodied tacit knowledge of engineers and technicians.

After the successful completion of the second group of substations a third cycle of the SECI process unfolded highlighting the continuous and everlasting nature knowledge creation. The Electrical Department head explained:

> "The second project for the substations did not cover all of the refinery needs. There were units that needed electricity supply. Therefore we decided to expand our network. The remaining units were "less important" than those covered by the first two substation generations. The budget could not cover the expenses for a contractor that would undertake the project. On the other hand the personnel had become extremely competent with the operation and the maintenance of the already established substations. There was accumulated experience by two different substation technologies. [...] We decided to take advantage of the personnel that had adequate time due to the fact that their experience enabled quick resolution of problems. There were also spare parts in the warehouse from the construction of the first two generations of substations, which would become obsolete because the substations did not face any particular problems. Hence, we constructed the third generation ourselves. [...] The results were more than satisfactory. We completed the project cheaper, faster and better."

The acquisition of personnel experience with two different substation technologies enabled them to develop a deeper understanding of their pros and cons. This, in conjunction with the condition of creative chaos that imposed an ambitious goal, the construction of a third substation generation with local resources and low budget, resulted to the creation of valuable technical knowledge on how to design and construct a new innovative generation of substations matching the local needs better than the previous two generations. The ED head also said:

> "We actually integrated the advantages of the two previous technologies. In the design and in the construction we used the personnel that dealt with the previous two substation generations. After 5-6 years of experience with the operation and maintenance of the substations we identified some things that could be improved. [...] We could improve the system in order to fit the local requirements. The first generation had some advantages, the second generation had some other advantages the third generation incorporated the advantages of the first two generations. The advantages had to do with the response of the units to the refinery demand (operational advantage) and some aspects that enable easier maintenance of the system."

The interactive SECI process took place not only within the Maintenance Division, but also inter-organizationally. The construction of the third generation substations involved many other departments such as the New Projects Department and the Instruments Department. The head of the ED said:

> "All new projects are executed with the responsibility of the New Projects Department. However they do not have the necessary expertise for the execution of the projects, therefore very often they use our personnel for the supervision of external contractors or for the execution of projects such as the third generation of substations. [...] The established network of substations changed completely the philosophy about the refinery control. So the Instruments Department was affected by these changes and we were in close collaboration."

The acquisition of competitive advantage by the above-mentioned successive rounds of the knowledge creation process becomes evident in another environmental fluctuation, the deregulation of the electricity market in the EU. The Greek government announced the deregulation of the Greek electricity market in 2000. The head of the ED noted:

> "The Executive Board asked from the Technical Manager to prepare a Feasibility Study examining the results from the construction of an electricity production unit. According to this study it would be beneficial for the Group to become an electricity producer. I was involved in the technical part of this study as well."

The feasibility study proposed also the utilization of maintenance personnel and local workforce, since the experience gained by the MD during the construction of the substation network could enable the construction of an electricity production unit. However, the nature of the new project was different from the establishment of the substation network. The ED head said:

> "The difference lies in the fact that in the case of the substation network we produce electricity in order to cover the refinery needs, in the second case we are establishing an electricity production unit that will supply the National Grid. It's a different scale project with different requirements. [...] Many Departments of the refinery collaborated for the establishment of the new electricity unit, the New Projects Department, the ID, the RED and our department. In the project were involved also Departments from the other refinery of the group. The decision to build the unit on our own was based on the fact that we had adequate experience in the turbine technology that would be used for the electricity production and in the electricity networks. [...] We were (Petrochem) the first company which acquired the license for the establishment of an electricity production unit, and if I am not wrong the first that managed to establish it."

The deregulation of the electricity market was followed by the submission to the Regulatory Authority for Energy of approximately six hundred applications for the acquisition of electricity production licenses creating an enormous market. On the other hand, knowledge created by the construction and operation of the substations network and the electricity production unit enabled Petrochem to acquire a competitive advantage, since the refinery developed a competent team able to provide its expertise and services at competitive prices to other companies that will attempt to establish similar units.

The above-mentioned example of knowledge creation is indicative of the continuous and dynamic interactions between tacit and explicit knowledge, whilst it also presents how the knowledge spiral becomes larger in scale as it moves up the ontological levels, from the level of the MD to the corporate level. Finally, the example provides insights about the management of knowledge creation, with top management providing the vision and middle management translating it into a successful application and providing certain conditions for the sharing of knowledge assets.

The story narrates how the smallest department of the MD at the beginning of the 80's, the ED, became a protagonist in developments in year 2000, after having experienced the incremental changes of a continuous knowledge creation process. This process was guided by the top management's vision to create a plant, which would be independent from power failures of the Public Electricity Company and was realized with the adoption of middle management's proposal to establish a substation network. The construction of the network was completed in many phases, during which the maintenance personnel acquired know-how in the construction, operation and maintenance of substations of various technologies. Furthermore, the last group of substations was constructed by local personnel with specifications set by refinery engineers and by utilizing warehouse spare parts from previous projects. The acquisition of competitive advantage from knowledge creation becomes evident during an environmental fluctuation, the deregulation of the Greek electricity market. Petrochem was the first company in Greece that broke the monopoly in this market by acquiring the first license for electricity production and by managing to construct the new electricity unit utilizing personnel from the MD. Petrochem acquired a competitive advantage with the development of a competent team consisting of refinery personnel able to provide its expertise and services at competitive prices to other Greek companies that would attempt to activate in this new market by establishing similar electricity production units.

Story B: Warehouse-Technicians or Originating Ba within the Warehouse Department

The following example indicates how the warehouse becomes a place for socialization in which technicians exchange experiences with warehouse employees and actually train them, in a rather unusual apprenticeship. This case is both an example of intra-firm information collection and also an example of internal tacit knowledge transfer. The workshop technicians help warehouse employees to understand the maintenance craftsmanship and transfer them expertise that is derived from accumulated experience and extensive practice at the workshops. This unexpected collaboration emerged due to the pressing need to identify quickly the required spare parts for each repair. Interviews with warehouse personnel recorded the story that describes a local particularity, the creation of a "new" specialty the "warehouse technician".

An engineer from the Warehouse Department explained that the identification of the required spare parts is often a problem in maintenance repairs at Petrochem. He also noted that warehouse personnel face both physical and organizational restrictions in the identification of a spare part explaining that the warehouse at Petrochem occupies an area of many thousand square meters, and it contains approximately two hundred thousand spare parts placed on five-meter tall shelves, whilst there is lack of effective warehouse management procedures and training. In addition, he said that the Computerised Warehouse Management System (CWMS) contains unreliable information concerning the spare part description, its location and its exact quantity. The issue of new spare part registration without a standardised procedure is an additional burden of organizational nature. The same engineer said:

> "Yes almost everybody from the Warehouse personnel registers spare parts, but the worst thing is that they have inadequate training about the types and names of spare parts. [...] In some cases, they do not have training concerning spare part types, names and identification at all. [...] It is very difficult to adopt one particular standard for naming the new spare parts."

In addition, lack of technical knowledge prevents the warehouse personnel from providing the expected services and this is extremely important especially in emergency incidents. Hence, shared context for socialization (originating Ba) is created spontaneously in order to cover this problem in the Maintenance Division, with the warehouse worker and the workshop technician joining forces and looking for the particular spare part in pairs. During this socialization process occurring at the corridors of the Warehouse that may last for many hours technicians transfer their experiences to warehouse personnel and explain to them how materials should be stored and handled, in order to be kept in good condition. The WD engineer said:

> "Well the technician and the worker spend much time together. Imagine a pair of two people. One of them, the warehouse worker, has some information about the spare part, such as the frequency of use, and the other knows the physical appearance of the spare part they are looking, knows how it is being used and where it will be used. It is a natural consequence that the warehouse worker learns a lot from this situation."

The warehouse engineer explained also that the warehouse worker provides information about the frequency of the spare part use from the CWMS. Moreover, warehouse workers after having spent so much time in their positions they have developed the skill to remember whether anybody else has used a similar spare part and other information not provided by the information system.

Furthermore, the phenomenon of the technicians wandering in the warehouse looking for spare parts with one of the warehouse employees is so frequent, that each maintenance department, except from the Planning, has one or two resident representatives there, who dedicate their time to this activity. These technicians act as catalysts of knowledge creation, since they move freely around the company and discuss with members across departmental boundaries and they create context for knowledge creation in which participants leverage their personal experiences. Technicians also act involuntarily as connectors of knowledge creation by creating a microcommunity of knowledge along with warehouse personnel, which promotes face-to-face interaction and especially the socialization process. These technicians have spent so much time in the Warehouse that they have become competent users of the Computerised Warehouse Management System with training they received from the warehouse personnel. Maintenance personnel have named these technicians "Warehouse Technicians". A warehouse engineer said:

> "They (warehouse personnel) learn very important things. For example some spare parts must be stored and handled in a certain way. Sometimes the suppliers give us such instructions, but the technicians do most of the work. However we train the technicians as well. Do you know that there are technicians fully trained in the use of the Warehouse management System? [...] Yes they have spent so much time in the Warehouse looking for spare parts together with our personnel that they started using the system. [...] Some of them have become extremely competent. I could say that they have become an extension of our personnel and they have acquired a new specialty. They have become "Warehouse Technicians".

In addition, this socialization process results in the creation of care and the sympathizing of the warehouse personnel with technicians, who sometimes "forget" the paperwork. An engineer from the Warehouse Department noted:

> "Despite the fact that sometimes they (technicians) do not charge the spare parts they take, and they also have an aversion to completing forms, in general they help us overcome the difficulties that stem from the poorly spare part classification."

Middle management is aware of this situation and approves it silently. In doing so, middle management, which has realized the benefits of this socialization process, plays the role of knowledge catalyst. The head of the Warehouse Department said:

> "Yes, technicians train the warehouse personnel. After all they use these spare parts and they have to inform us, and why not train us, if they want us to treat these parts appropriately."

Furthermore, the head of the Warehouse Department acts as a merchant of foresight by providing direction to the knowledge creation by his department. The department head is aware of the existing problems of his Department, however, he also shows the direction by providing a vision for the management of the warehouse in the near future with the use official training and advanced technologies. The head said:

> "Yes, if they (warehouse personnel) were more trained they could handle some situations more effectively. [...] Materials storage and handling can be a very interesting subject, especially in a Warehouse of our size. We could do plenty of things such as a pilot project for stock control with sensors."

Finally, the inquiry provided indications about the transferring of knowledge to newcomers from their senior colleagues in an apprenticeship, due to lack an official training programme. An engineer from the Warehouse Department said:

> "There is not an official training programme for the Warehouse personnel. They (warehouse personnel) come here and learn things by watching others. Of course the more experienced workers teach them how to use the Warehouse Management System. Then we send them outside to start learning the different spare part areas."

Story C: The Brush Story

The Brush story is maybe the most popular story amongst the personnel within Petrochem and its Maintenance Division. An engineer from the RED and an engineer from the Operations Division in separate interviews narrated the following fictional story:

One day a supervisor asked from a worker to get a bucket full of paint and start painting a huge surface. The manager told the worker to get a brush in order to do the job. The worker following exactly the orders of his supervisor got the paint and the brush and started his job immediately. An hour later the supervisor came up to inspect the progress of the job. Despite the fact that the worker was doing his best, the surface was huge and he had only painted a small part of it. The supervisor was not pleased by this and asked the worker to get a second brush and use both hands in order to speed up the job. The worker got the second brush and continued the job. An hour later the supervisor came up and realized that the worker was doing Ok, but he wanted to finish the wall by the end of the day. The supervisor advised the worker to speed up. The worker said that he was doing his best since he was using both hands. The supervisor had a different opinion and replied that he should get a third brush, put it in his mouth and complete the job by the end of the day!

The MD engineers explained that the story is used mainly by supervisors and technicians in order to describe the pressing need to complete maintenance tasks for which there is limited available time is, whilst the workload is huge. Personnel do not narrate the same story each time, since they assume that all of their colleagues are familiar with it. The investigator has heard many times supervisors saying to their technicians, "Get a brush!!!", referring to this story.

Appendix Four - Petrochem's policy on social responsibility

Petrochem declares in every annual report since 1998 that: "Participation in social developments is one of the characteristics of a modern enterprise, as industrial/commercial activities must be combined with a positive response to social requirements." Furthermore, Petrochem Group consistently declares not only in every annual report, but also in many internal and external announcements that its objectives "are not restricted to the provision of low-cost and high quality goods and services. They extend to sectors such as the responsible management of natural resources, environmental protection, the rational allocation of its social product and the most harmonious combination possible of human and capital resources that make up the enterprise. The creation of a feeling of trust, cooperation between social partners and respect for human values constitute options that are ultimately in line with the objective of maximizing financial results. The size of the Group, the wide range of its activities and the resulting impact on the social environment are reflected in the size and composition of its social product. In an era when issues of social cohesion carry particular weight, the Group's economic contribution to society is of special importance. Petrochem's contribution to the social product is represented by the disbursements to its employees in the form of salaries, to social security and pension funds, the State and funding sources (shareholders and banks)."

In addition and besides environmental considerations, Petrochem has an established policy to organize guided educational tours within its venues to pupils, students and scientists from schools, universities and institutes from all over the country. Thus, within this framework of communication policy and continuous cooperation with the country's educational institutions, the Group's industrial venues in 2001 were visited by students of three elementary schools, 40 secondary schools, four technical colleges, five university departments, trainees of the Fire Service Academy.

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