

Article

Analysis for the Knowledge Management Application in Maintenance Engineering: Perception from Maintenance Technicians

Javier Cárcel-Carrasco ^{1,*}  and José-Antonio Cárcel-Carrasco ^{1,2} 

¹ Department of Architectural Constructions, Universitat Politècnica de València, Camino de Vera s/n, 46022 València, Spain; jacarccl@tecnatom.es

² Tecnatom S.A., C.N. Cofrentes s/n, Cofrentes, 46625 València, Spain

* Correspondence: fracarc1@csa.upv.es; Tel.: +34-96-387-7000

Abstract: Knowledge based on personal experience (tacit knowledge) acquired in problem solving actions and in maintenance actions is the fundamental basis for maintenance technicians in companies with great physical assets. Generally, there is no proper policy for managing strategic knowledge and its capture. In this article, through qualitative studies (grounded theory) and surveys conducted with technicians, the aim was to obtain the perception of the maintenance technicians' part of the companies, in order to establish the characteristics of the relation between the strategic aspects and the engineering aspects of industrial maintenance, regarding knowledge management, as well as the enablers and barriers to its application. The results show how a high level of tacit knowledge is used in this activity, which requires more time for new staff. The values obtained from this survey show that the knowledge recorded by the companies (explicit) is 51.25%, compared to the personal knowledge (tacit) of maintenance technicians regarding reliability and breakdowns. In operational/exploitation actions it is 43.90%, for energy efficiency actions it is 49.61%, and in maintenance actions (preventive, predictive, and corrective) the value is 68.78%. This shows the significant gap between the perception of recorded knowledge (explicit), and the knowledge that maintenance technicians have (tacit knowledge). All this can affect the companies, as part of the strategic knowledge is lost when a maintenance technician leaves the company.

Keywords: knowledge management; industrial maintenance; tacit knowledge; large building maintenance; Industry 4.0



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1. Introduction

In industrial maintenance engineering, in companies with large physical and productive assets or buildings, knowledge of facilities is essential, since it is key in transforming tacit knowledge into explicit strategic knowledge of the operational experiences of the maintenance technicians who operate them. An in-depth study of these measures will lead to energy efficiency and the improved reliability of the processes and production of the company.

The main indicators of maintenance efficiency are based on various pillars, such as reliability, availability, maintainability, safety, operating costs, and the human factor, which is a fundamental one for operability, and in which operates a high level of tacit knowledge that is generated by people in the performance of assigned maintenance tasks. The reliability of the machines or systems requires a high level of knowledge and experience, and is linked to the study of the failure process, including the aspects of reliability and quality of the work that maintenance departments carry out [1–6], and it is possible to establish new indicators that allow estimating the security level of these systems, and which describe the impact on infrastructure, and the associated risks [7,8].

The term “Industry 4.0” refers to the latest industrial revolution, which uses artificial intelligence to greatly change the way in which machines and facilities collect and interpret

data and information [9,10]. However, a lot of information (often strategic) is in the hands of maintenance technicians, based on their own knowledge of the workplace (tacit knowledge), and which is lost when a technician leaves the company.

The technicians which work in the maintenance departments of companies, normally operate using their professional experience acquired from years of experience, which has a high component of tacit knowledge, and traditionally without knowledge management policies being applied in these companies [11,12].

The fundamental factors that determine operational reliability (human and technical) of maintenance departments must be taken into account [13–16]. Exploitation operations (also called facilities management) are the normal processes that happen during the production or service provided by the company, which involves utilization of the facilities, rearming of switches, start-up manoeuvres, stopping processes, etc.

An adequate maintenance management connects and transmits information between the departments of a company, but also between sensors, devices, or systems. It also transmits information between maintenance technicians themselves [17–20]. Through the data collected, the new devising of maintenance solutions can generate strong analyses, in order to support professionals in decision-making and troubleshooting actions [21,22].

The main advantage of predictive maintenance is the reduction in maintenance interventions or unscheduled breakdowns, based on data from sensors, equipment vibration, lubrication, noise, or increases in temperature. Once they are properly evaluated within the maintenance management solution, and analyzed with the available data on equipment (intervention history, management of spare part information), these measures can predict the occurrence of a breakdown, repair, or replacement [23–26].

Therefore, the solutions of Industry 4.0 should allow companies to implement preventive maintenance and actions to improve reliability, troubleshooting, energy efficiency, and the normal actions of facilities usage [26]. Maintenance technicians can improve cycles and adjust maintenance monitoring parameters over time, as well as add new parameters. The maintenance knowledge and instructions library can also be expanded and updated, which leads to a continuous improvement in repair and operating times.

The concepts of Industry 4.0, big data, and predictive maintenance (PdM) are closely related [19,27,28]. PdM relies on monitoring machinery in order to optimize maintenance tasks, so that repair tasks are only executed when it is strictly necessary. The main value of this system is the notification of abnormalities or failures in development, which allow the scheduling of maintenance tasks, and thus, the risks and costs of unexpected breakdowns are minimized, and the industry has a greater awareness of the possibility of optimizing the operation and maintenance of assets through data on their current status or forecasted status, on their operation, or the quality of the manufactured product.

The relation of Industry 4.0 with maintenance departments is important due to aspects such as updating, efficiency, and monitoring, being important tools to take into account, and also due to the interaction capacities, and the information exchanged, between humans, machines, and facilities; favouring the construction of capacities which allow companies to adapt to changes. All this involves proper knowledge management in the philosophy of Industry 4.0 [29–32].

For this reason, technicians who work in this activity need highly sophisticated technical and knowledge components, and the human factor is implicated highly in their performance, with a high degree of tacit knowledge; although in this activity, organizational factors, behaviour of materials, and failure, are also widely studied. Regarding the knowledge management process, it is not conducted in the same way, although in other departments of the company (marketing, commerce, development, communications, etc.), it has begun to be introduced, as another benchmark of competitiveness and innovation [33–37].

Therefore, the starting point is the visualization of knowledge management as a strategic resource [38], in any approach aimed at the efficient development of a maintenance department, and therefore of the company itself.

For this reason, it is important to define and extract the mechanisms of structural coordination, facilitators, and creation of knowledge [39], which occur in a maintenance organization, improving its operational processes [40,41], and transmitting an improvement throughout the company, and with it a management of human resources towards the achievement of knowledge management [42] with a useful and productive purpose. This knowledge management process must be taken into account within the maintenance activity, which consists basically in the generation, coding, transfer, and use of knowledge [43–45].

This article shows the result of a study carried out among maintenance technicians of large companies, using qualitative research techniques, whose main objective was to define the relationship of knowledge management within maintenance activities, from the perspective of the technicians which operate in these departments, visualizing the strategic aspects that make knowledge management important in maintenance engineering, as well as extracting the fundamental barriers and facilitators that these technicians consider for the creation, transmission, and use of this strategic knowledge. The maintenance technicians, who participated in the study, work in different types of industries in Spain, although the activities done by technicians are similar (maintenance actions, troubleshooting, maneuvering actions for machines and industrial process equipment, and energy efficiency actions, etc.). All this can affect the companies, since part of the strategic knowledge is lost when a maintenance technician leaves the company. From the study an important difference was observed between the perception of registered knowledge (explicit), and the knowledge that maintenance technicians have (tacit knowledge).

2. Instruments and Methods

A working hypothesis was made on which this research was based, in order to analyze the implementation of knowledge management in maintenance engineering among maintenance technicians, based on their perception while working in the companies:

- (a) Maintenance technicians operate with a high component of knowledge that is not registered in the company (tacit knowledge).
- (b) Tacit knowledge directly impacts on the resolution of critical actions and breakdowns in a shorter time (especially the non-cyclical ones), operational maneuver time reduction, and improvement in knowledge for detecting and improving energy efficiency.
- (c) The use of knowledge management techniques in maintenance activities, consequently, induces a reduction in the operational familiarization time of new staff.
- (d) Proper knowledge management by the maintenance organization positively influences the operability of the company and the connection of work teams.

The instruments used in this research were: the semi-structured interview and analysis done by grounded theory; direct observation and company documents related to the study phenomenon were the main data collection methods in this investigation. Collecting information from various sources, people, or sites, using a variety of methods reduces the risk that the conclusions reflect only the predispositions or limitations of a specific method, allowing a better evaluation of the validation and generalization of the results [46].

All this is focused on showing the different barriers and facilitators to implementing knowledge management techniques in industrial maintenance activities, and detecting their involvement in the essential factors considered in maintenance (reliability, performance in operational activities, maintainability, and energy efficiency). For this, qualitative research techniques were used in various phases, in order to detect the evolution in companies, the evolution in maintenance departments, and the involvement of people.

In qualitative research [47], being objective does not mean controlling variables but being open, having the will to listen and “give voice” to the interviewees, whether they are individuals or organizations. It means listening to what others have to say and seeing what others are doing, and representing them as accurately as possible.

Grounded theory (within qualitative techniques) [48,49] was in the analysis of the research data. For this, the process indicated by Charmaz [48] was followed: (a) data

collection through theoretical sampling; (b) initial coding; (c) oriented coding; (d) elevation of the codes to provisional categories by theoretical coding; and (e) writing the obtained results.

The main characteristic of grounded theory research is theoretical sampling, selecting cases according to their potential in order to obtain new points of view and a refinement of the object of study [50].

With the implementation of grounded theory, the following results should be obtained [51,52]: (a) Obtain an exposition of the main variables that explain how the studied group solve their problems; (b) The results obtained identify the basic processes that people use to solve key problems; (c) It is not enough to describe the phenomenon. It is necessary to go one step further, and to interpret and explain what is happening.

Through observation techniques, an attentive examination of the different aspects of a phenomenon is carried out in order to study its characteristics and behaviour within the environment in which it develops. It is a technique that consists of observing the fact or case, taking information, and recording it for subsequent analysis.

Direct observation of phenomena helps to provide appropriate methods for the problem to be studied. In addition, among other advantages, it allows for the global presentation of research, including plans and the use of techniques and tools.

The phases of this research for achieving the defined objectives can be summarized with the following characteristics:

- (a) First, using grounded theory, 76 people belonging to operational maintenance staff from different sections were interviewed (Table 1). At the same time, the direct observation technique was used, during this research phase, with access to the facilities, documentation, and equipment of the factory by the researcher, the real characteristics of the work carried out in maintenance, the study of their internal relations, and the characteristics of the information used by the maintenance teams were recorded, giving the researcher an insight into the phenomena in the research environment. With this, an attentive examination of the different aspects of a phenomenon is achieved, in order to study its characteristics and behaviour within the environment in which it develops.

Table 1. Features of the sample of the technicians interviewed.

Labor Category	Work Experience (under 5 Years)	Work Experience (between 10 and 15 Years)	Work Experience (>15 Years)
operational maintenance technicians. (mechanics)	6	12	9
operational maintenance technicians. (electrical-systems)	10	9	7
operational maintenance technicians. (production)	9	8	6
subtotal	25	29	22
total		76	

The format of the questions for the individual interview (and also used in other qualitative techniques) was based on 22 basic questions, the basic script of the interview being as follows:

- Based on your experience in the field of industrial maintenance engineering, it is intended to study the strategic factors of maintenance, and their relationships and evolution with knowledge management processes, answer the following questions:
- Q01. What do you consider to be the strategic activities of the maintenance activity that most affects the company?

- Q02. To what extent do you think the experience of technical maintenance personnel affects these strategic activities?
- Q03. What level of information/knowledge do you manage at your own level regarding maintenance activities (tacit knowledge, not registered), and what is precisely documented in the company (explicit knowledge)? Can you give an example?
- Q04. From the explicit information that the company may have access to in order to carry out their work (computer programs, machinery, and equipment manuals, planimetry, work orders, etc.), to what extent is it useful and what deficiencies do you observe?
- Q05. How do you document or transmit your daily jobs/experiences in your maintenance job, and how much time do you spend on it?
- Q06. What is the usual way in which you capture the (important) operational experiences of your colleagues (through meetings, informal conversations, etc.), so that you can resolve such an action when it happens to you (example: operational manoeuvres in the event of breakdowns) or perform this task (example: maintenance work)?
- Q07. Has a knowledge management program been implemented in your organization involving tactical maintenance actions? If yes, what opinion do you have of it?
- Q08. What information/knowledge should be captured or made explicit, that helps you in the performance of your duties?
- Q09. How should such information/knowledge, its accessibility (to share it), and its maintenance (how to collect and update it) be structured, so that it is easily usable and accessible to you?
- Q10. What would be the benefit of the capture and conversion of tacit to explicit knowledge, personally and at the company level?
- Q11. What would facilitate, in your opinion, the capture and conversion of tacit to explicit knowledge? How should such knowledge capture be done?
- Q12. Which barriers do you consider most important for the implementation of a knowledge management program in the maintenance activity?
- Q13. What would motivate you to support and be interested in capturing and recording your tacit knowledge and that of your colleagues, and which could improve the work of your colleagues and help improve the productivity and efficiency of the company?
- Q14. What type of actions/experiences should be documented that affect the tactical actions of maintenance engineering, such as: Reliability of equipment and systems, Operation/operation of facilities, Energy efficiency, Maintainability?
- Q15. How do you think it would affect the familiarization time of new personnel, and the action times of all maintenance technicians, if information structuring the and capture of tactical actions, as well as operational experiences lived, were based on experience?
- Q16. What factors should be controlled quantitatively (measured), to see what affects the improvement of knowledge management in the tactical actions of maintenance?
- Q17. Before a new installation, machinery, reform, etc., would it be convenient to introduce in the gant/pert diagrams of the duration of the works, a new activity in which the registration and collection of practical and useful knowledge is found, reflecting the actions or relevant information that would help in future installations?
- Q18. What tools/techniques, means, etc., do you think would help you capture the important tactical and strategic information in your maintenance activity?
- Q19. In your opinion, what consideration does the company's management and maintenance clients (production, other areas of the company, etc.) have of the activities and missions of the maintenance department?
- Q20. Do you need to know more about these topics, with reference to knowledge management of maintenance activity? What knowledge gaps do you have on these topics, which prevent you from getting more out of it?

- Q21. What type of training would it be appropriate to receive, to what degree and in what way, that could improve your work efficiency?
- Q22. Enter below any information or suggestions that you consider relevant, and that have not been addressed in the questionnaire.

The data was analyzed with the help of the Atlas.ti 5.0 application from ResearchTalk Inc. (Berlin, Germany) [53–55].

- (b) With the aim of deepening the perception of knowledge management on the strategic actions of industrial maintenance engineering (reliability, operations, energy efficiency, and maintainability) by maintenance technicians, and allowing much greater access to it, by a greater number of members of the operative staff (Table 2), a survey (Figure 1) was passed to all the operative personnel (174 technicians) in order to identify and quantify their perceptions, about the personal knowledge they use (tacit) and the knowledge that they perceive as documented in a useful and precise way by the organization (explicit), regarding factors involved in the performance of their functions.

Table 2. Survey population based on years of maintenance experience.

Technicians' Work Experience (years)	Number of Surveys
<3	34
3 to 5	48
>5	92
total	174

A-10 KNOWLEDGE MANAGEMENT IN ING. OF MAINTENANCE TOWARDS STRATEGIC CRITERIA (A-10 TACIT AND EXPLICIT KNOWLEDGE IN THE ORGANIZATION)

001. Globally ponder **your** level of knowledge or **tacit** information (which you manage, due to your experience and performance, and is not documented in the organization) on the factors indicated below, which you use in the performance of your work, in relation to the **explicit** information (fully documented and very clear by the organization). (value 1: Little knowledge or documentation; value 5: Excellent knowledge or documentation). EXAMPLE: in item "a) RELIABILITY", I can estimate that my level of knowledge in solving failures and dealing with faults is "4", and the documentation that I perceive or exists in the organization to solve clearly and efficient failure processes I estimate "1"

a) **RELIABILITY AND FAULT PROCESS:** I know with precision the possible failures and resolution of faults, I know how to proceed, on what points to act, what tools or spare parts to use, I look for solutions and analyze possible faults that could occur to take them into account.

Your Knowledge: Useful and accurately documented in the organization:

1 2 3 4 5 1 2 3 4 5

b) **OPERATION / EXPLOITATION:** I know in front of operations of the equipment, machinery or facilities, the position of the key elements, I know the layout of the factory and where the manoeuvring elements and actions to be carried out in them are located. Critical elements will be maneuverer.

Your Knowledge: Useful and accurately documented in the organization:

1 2 3 4 5 1 2 3 4 5

c) **ENERGY EFFICIENCY:** I know the energy process, possible variations in energy expenditure of equipment, machinery and facilities according to their use. I can estimate and detect improvements that result in the energy efficiency of a complete system or equipment. I propose improvements in energy matters.

Your Knowledge: Useful and accurately documented in the organization:

1 2 3 4 5 1 2 3 4 5

d) **MAINTAINABILITY:** I know precisely the routine maintenance work, the factors and the methodology to use. In periodic maintenance work, be the complete process to be carried out, the tools to be used and the necessary material or spare parts. Fluent handling of measuring and testing equipment used in maintenance techniques.

Your Knowledge: Useful and accurately documented in the organization:

1 2 3 4 5 1 2 3 4 5

Figure 1. Survey format, among technical maintenance members.

3. Results

As results, the different elements detected in the qualitative research from the perception of the maintenance technicians in relation to knowledge management in the activity of the company, in relation to strategic maintenance actions, and the involvement of operators, are listed, as well as the quantitative perception that they had between their own knowledge (tacit), and the explicit knowledge which is registered in the company.

Sections 3.1 and 3.2 show the results obtained, based on the usage of the grounded theory technique through semi-structured interviews held with 76 maintenance technicians.

3.1. Relation between Knowledge Management and Fundamental Strategic Maintenance Actions

From the qualitative study based on interviews with maintenance operators, it was confirmed that proper knowledge management would greatly affect strategic activities, improving the following actions:

- Capture of the tacit strategic knowledge from operational maintenance technicians.
- Resolution of critical failures in a short period of time (especially non-cyclical ones).
- Reduction of operating manoeuvre times.
- Facilitate the change of area or staff substitutions.
- Decrease in the engagement times of new staff members.
- Information capture and transfer of subcontracted companies.
- Sharing of employee knowledge that can be used by others, who can detect new opportunities for improvement.
- Improved knowledge of the reliability of equipment and facilities.
- Improvement of knowledge for the detection and improvement of energy efficiency actions.
- Time optimization, with effects on knowledge management and the reduction of maintenance costs.

Maintainability: This affects all the equipment and infrastructure of the company. It considers the great variety of processes and actions needed to perform efficient maintenance of each of the elements, and which requires a great deal of experience and knowledge. The adaptation of employees to carry out maintenance work occurs through knowledge of the environment, where the facilities are located, and normally acquiring the necessary knowledge by observing and commenting on employees with more experience, until being fully autonomous in those activities. They consider employees with less work experience a delay in carrying out the processes to be executed. All consider that, even though it is the activity that is most documented within the organization, due to the use of computerized maintenance management programs, the actions to be carried out and useful anecdotal experiences are not usually documented, and should be experienced by the operators that have not been through a particular situation.

Reliability: The main demand of the production departments is to avoid stoppages of the equipment and the dependent facilities for production. Interviewees considered that the knowledge of cyclical and non-cyclical failures has been acquired based on experience in their performance, with greater security in the prevention and resolution of breakdowns by more experienced employees. The resolution procedures are not usually documented, the learning process having been carried out based on a trial and error process and informal comments from other employees who have experienced these situations previously. Diagrams of criticality and failure processes are not usually made, and regarding critical non-cyclical actions, a very significant loss of time occurs in the resolution of a breakdown, which economically affects the company, due to the excess time spent in the replacement of the service.

Energy efficiency: This is of high economic relevance as it affects the final price of the products made by the company at an economic level. It is the most controlled strategic action by the company's management, and effort is normally focused on the quantification of general energy consumption or the revision of rates by the supply companies. All considered that there are numerous actions for energy efficiency of little expense (review of

useless consumption, valve closures, control of consumption of machinery in the process of production stoppage, etc.), however they are not usually documented. Many of the low-impact actions are carried out directly by the operators using their good know-how, due to their own experience in the factory, and knowing the characteristics of the manufacturing processes. Employees take time to adapt, and only when you have consolidated experience in the factory do you gain enough knowledge to make useful decisions in that direction. It is recognized that with the adoption of many of these small energy efficiency actions, it is possible to achieve significant savings, as well as anticipating and planning new actions that will result in their improvement.

Operation/exploitation: These are normal actions in a factory's operating cycle (facilities manoeuvres, machinery shutdown and rearming processes, actuation of automatic switches by a trip, etc.). Operational actions directly affect the efficiency of the processes or services provided. All the interviewees agreed that with a change in maintenance personnel or the subcontracted company there is a loss during the first months of operation from the new personnel is recruited, until there is a greater knowledge of the facilities and characteristics demanded by the company. It is recognized that the subcontracting processes means that the subcontractor company manages a strategic knowledge of the company itself, which is normally lost due to a change or substitution of such a company.

3.2. Operators Involvement

The involvement of operators is another key facilitator of sustainability in a maintenance knowledge management project, which was verified in this research. They must be fully involved as a fundamental source of strategic knowledge and of the improvements developed, as well as the base of ideas and part of the improvement process. Without the participation and involvement of operators, the knowledge management project is doomed to failure, since it must, as a principle, involve all members of the organization. To get the involvement of the operators requires training, support, and explicit recognition by the company management and maintenance managers.

A large part of the interviewees reacted very positively to the introduction of material incentives based on improvements achieved by the work, both in groups and individually. When starting a knowledge management (KM) project, it is advisable to have incentives, but once the culture has been assimilated, they consider the express recognition of the company as sufficient.

At an individual level, personal motivation, and the opportunity to learn and facilitate the generation of knowledge, which is shared with other members of the group, gives rise to organizational knowledge.

3.3. The Quantitative Perception of Maintenance Operators

In order to estimate the differences in perception between the knowledge based on maintenance operators own experience, in relation to the knowledge that they perceive to be explicit in the organization, a questionnaire (Figure 1) was passed to all the maintenance operating personnel of the organization (174 maintenance technicians), comprising four items, subdivided between the two perceptions. Based on a maximum knowledge index valued of five, the following means were obtained based on the different strategic activities (Figure 2), and the seniority of the operators.

It was observed that the knowledge that the operators use to carry out their daily actions, is based mainly on their own (tacit) knowledge, considering that many of these actions are not included in the explicit knowledge of the company. This was observed to a greater extent among older operators, where such contrast was much higher.

Figure 3 shows a radar-type graph, where it can be seen, according to the study, the comparison between the operators own strategic knowledge, in contrast to that explicitly provided by the maintenance organization from the perception of maintenance technicians. Although it was based on a subjective view on the part of the operators, for all of them a higher level of perception of their own knowledge, as a mechanism for the performance of

their fundamental missions was reported. There were higher levels of knowledge on the part of the operators and in the organization on maintenance actions. This may be mostly due to the fact that it is where the bulk of the maintenance department’s information and procedures are normally concentrated (maintenance management programs, maintenance estimate tables, etc.). In the same way, it can be concluded that the level of tacit knowledge compared to the explicit knowledge of the organization, increased due to the increase in seniority, and therefore the experience, of the operators.

KNOWLEDGE BASED ON THE EXPERIENCE OF THE OPERATORS IN THE COMPANY

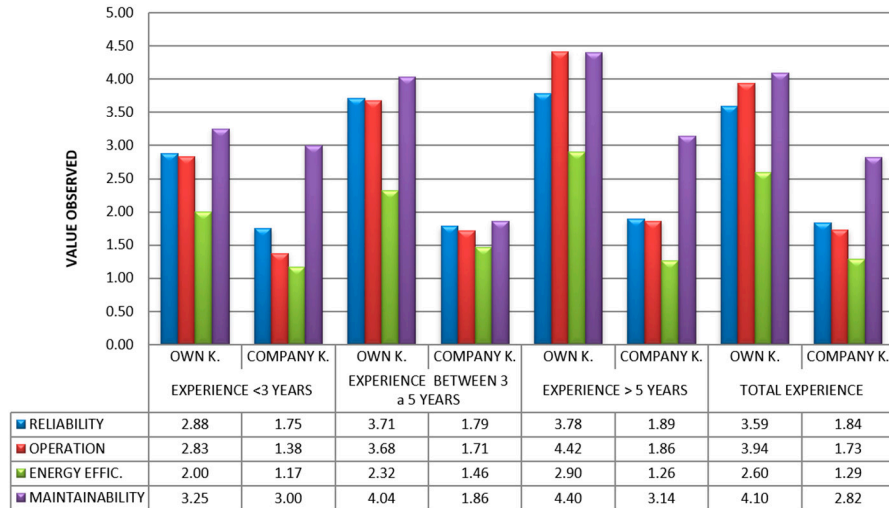


Figure 2. Graph of the relation between own knowledge vs. knowledge registered in the company regarding the strategic activities of the maintenance department (reliability, operation, energy efficiency, and maintainability) according to the perception of maintenance technicians.

RADAR OWN KNOWLEDGE Vs COMPANY KNOWLEDGE

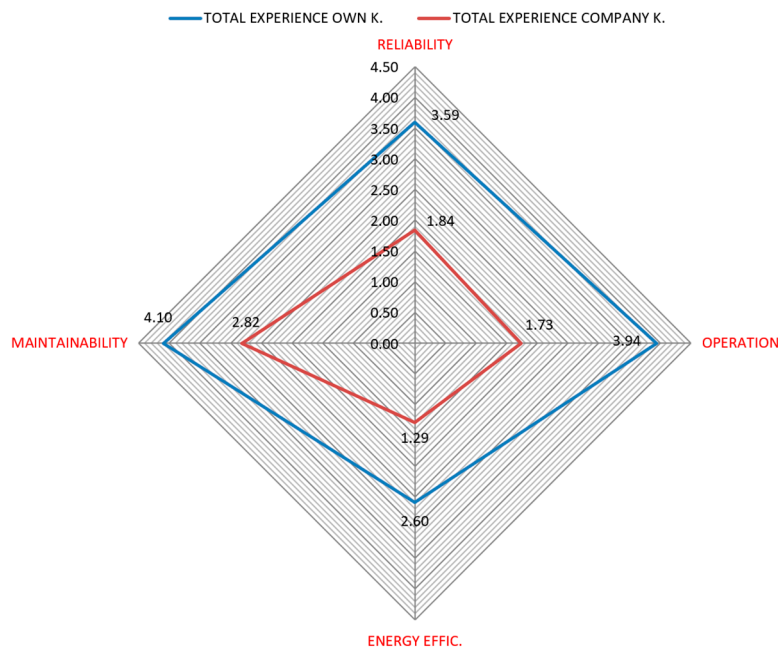


Figure 3. Graph of the relation between the technicians’ own knowledge in relation to the explicit knowledge in the company.

4. Discussion

The fundamental barriers found by this study for the adequate management of knowledge in the maintenance activity according to the perception of the technicians of these departments, were the short period of time available to properly document some important actions, and the existence of cultural barriers, with a culture based on “own knowledge”, that is not shared, especially by the operational technicians, as well as getting the full involvement of the staff. This study confirms some processes and actions that must be taken into account when proposing a knowledge management model in this activity:

- The normal process of familiarizing the staff to the conditions of the company relies on tacit knowledge (learning based on experience in the environment), which involves this internal knowledge and the way to make it explicit to the entire organization [12].
- This coupling is necessary before operators with experience in the company change their environment (by changing to another headquarters or changing the work section).
- The usual process is to learn the actions based on others experience in carrying them out over time.
- There is a unit of operators with more experience and knowledge of the facilities and equipment.
- Knowledge about solving breakdowns is critical since it strongly affects the production of the company or the service it provides.
- Experience in the resolution of non-cyclical breakdowns is not usually documented, and the resolution process starts from scratch when it happens to an operator who has not gone through such an experience.
- There is usually no critical study of reliability or a crisis knowledge map. In-depth knowledge of key processes is required.
- The knowledge process in the routine actions of operation, is characteristic of the facilities of each company and involves a familiarization time for maintenance technicians.
- Such operational actions directly affect the efficiency of the processes or services provided.
- In-depth knowledge of the facilities and equipment is necessary to determine the best energy efficiency options.
- Many of the energy efficiency options are observed during the operation of the facilities, with simple implementations, which are not normally realized or executed, due to factors related to the poor transfer of information, or the knowledge of the operators who observe them.

Similarly, the massive use of informal knowledge transfer mechanisms has been identified, with information being found on “islands” within the organization itself. A large volume of tacit knowledge handled by the operators is present, and which is the fundamental way of operating, compared to the explicit information or knowledge of the organization (Figure 4).

As can be observed in Figure 4, the perception of maintenance technicians, between their own knowledge (tacit knowledge) and that registered in the company (explicit), varies considerably. If we compare the values obtained for this perception, it is seen that the knowledge registered in the company (explicit) is 51.25% (1.84/3.59) compared to the knowledge of the maintenance technicians (tacit), for the case of reliability and fault resolution. In the case of operation/exploitation share, it is 43.9% (1.73/3.94); for energy efficiency actions 49.61% (1.29/2.60); and in maintenance actions (preventive, predictive, and corrective) 68.78% (2.82/4.10). This shows the significant gap between the perception of the registered information (explicit) and that maintenance technicians have by themselves (tacit knowledge), based on their experiences accumulated over years in their jobs. All this can affect the company regarding staff modifications (layoffs, staff reductions, sick leave, staff retirements) since part of the strategic knowledge is lost when a technician leaves the company.

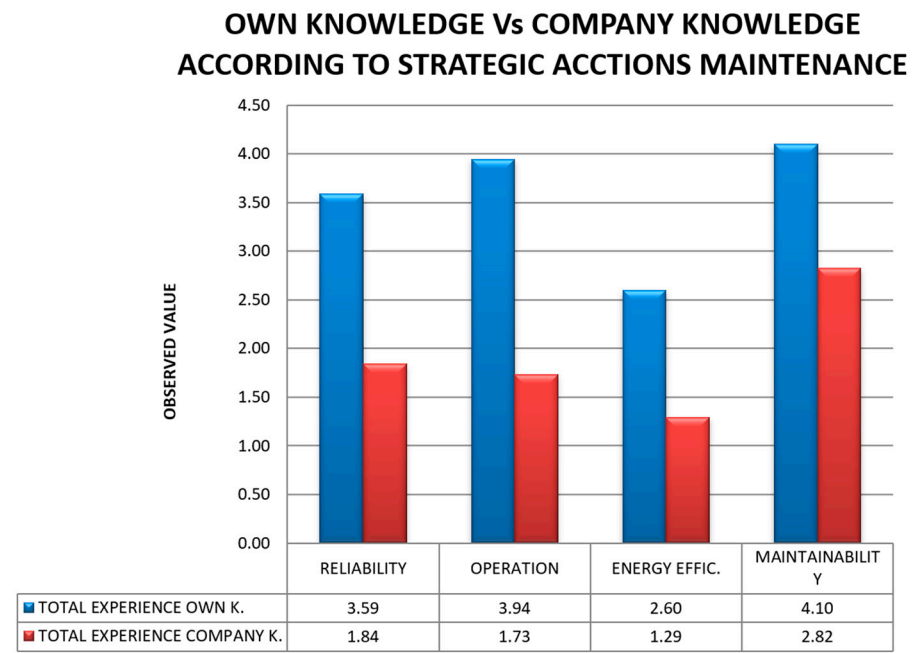


Figure 4. Graph of the relation between the technicians' own knowledge compared to the explicit knowledge in the company based on the strategic aspects of maintenance.

The perception of the maintenance technicians was that they have limited awareness in knowledge management techniques, normally functioning as “islands of knowledge” within the department. Moreover, the vast majority consider that they need training applied more to the company's own facilities (they suggest that the training they normally receive is very generic on technical aspects of electricity, mechanics, etc.).

This study confirms the importance that adequate knowledge management can have on the fundamental strategic maintenance activities, and which was confirmed by all the interviewed personnel (reliability, maintainability, energy efficiency, and operation/exploitation). In Figure 5, the main observed characteristics are extracted based on the processes and strategic aspects of maintenance, and the result on the efficiency of the company's activity.

It is recognized that an improvement in the management of information and knowledge, positively effects all these actions, and especially in the resolution of major breakdowns, or non-cyclical failures spaced in time, and with their performance not normally recorded.

As for the tools that can be used for the strategic information capture that helps improve knowledge management, they are normally little used in all maintenance environments. There is a low use of audits on internal actions, information and knowledge maps are recognized, and criticality diagrams are made only for certain facilities or equipment essential for the company's activity.

A greater use of informal meetings was suggested as a means of generating and transferring knowledge, especially among groups of operational technicians, who have less of an organizational culture than the managers or maintenance managers.

The participants in the analysis considered that applying their own knowledge on organizational activities would motivate them in fields such as self-learning, learning new tools, and creating new ways of executing different activities. When this personal motivation is reinforced by knowing that their opinions and suggestions to acquire external knowledge will be taken into account, the processes of knowledge transfer and usage are enhanced.

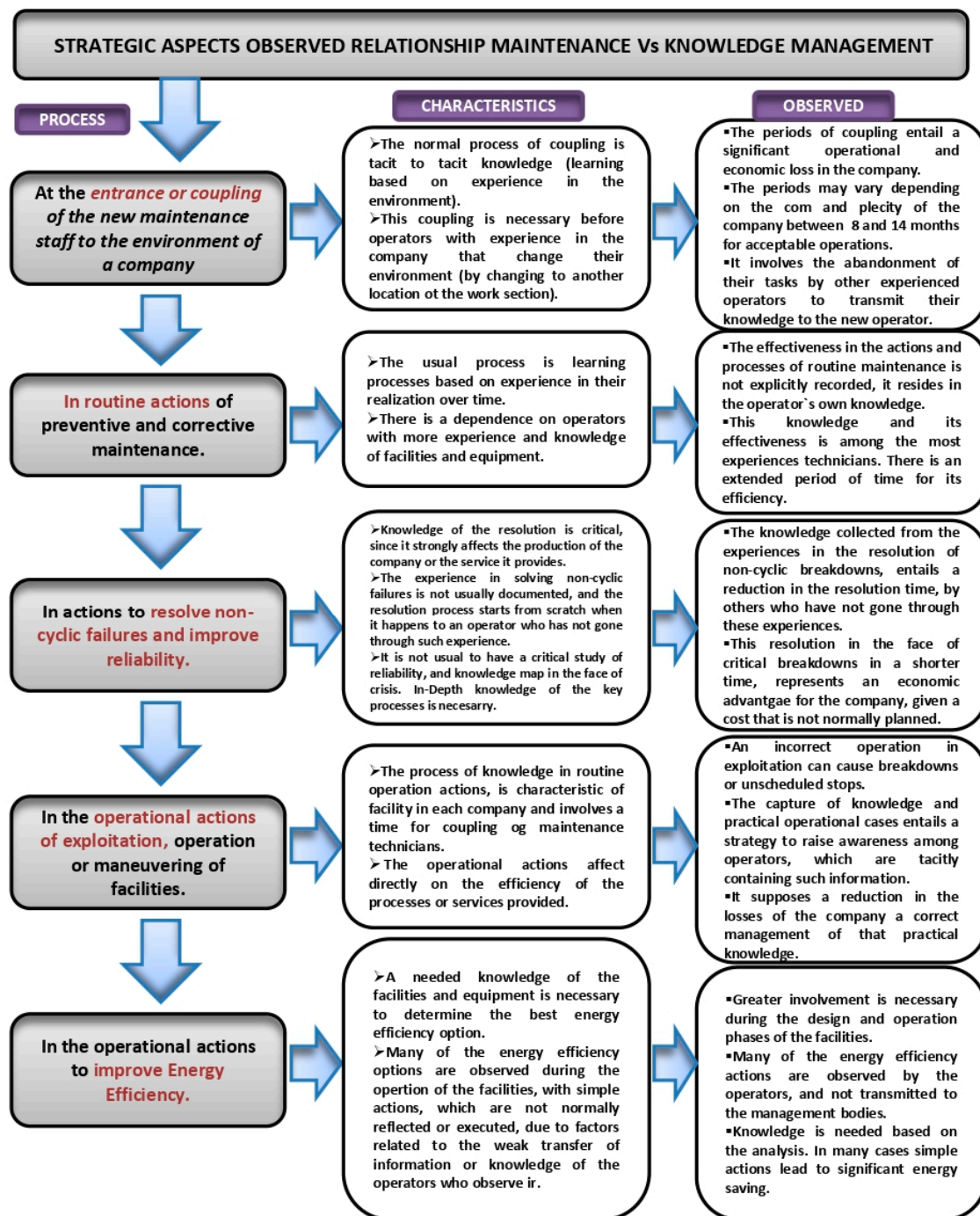


Figure 5. Strategic aspects of maintenance and its relationship with knowledge management.

Table 3 shows a summary of the main characteristics that have been identified in the present study in terms of tools, barriers and facilitators, and implications in the knowledge management processes, according to the perception of maintenance technicians.

According to maintenance technicians, personal motivation and learning opportunities promote the creation of knowledge, when the knowledge is shared with other members of the company organizational knowledge is created, and the open culture of the organization enhances the organizational knowledge. The research participants thought that being able to use their knowledge in organized activities would motivate them in self-learning, to learn new tools, and create new ways of doing activities. This would improve knowledge

transfer, when this personal motivation increases by knowing that their opinions and suggestions about acquiring external knowledge will be considered.

Table 3. Tools, barriers, and facilitators in the K.M. in maintenance activity according to the perception of maintenance technicians.

Category of the Studied Phenomenon	Maintenance Operational Technicians
Tools for knowledge management	Information and knowledge maps. Agile and simple systems to capture experiences. Mobile computing tools to capture images, videos, and experiences.
Barriers in Knowledge Management	Little time available to properly document important actions. Cultural barriers. Culture based on “own knowledge”, not shared. Staff involvement. Greater use of informal knowledge transfer mechanisms.
Facilitators in Knowledge Management	Open and flexible proactive organizational culture. Participatory style of management. Employee’s personal motivation. Opportunity to learn. Organizational culture of the maintenance area. Management style. Media. Use of a manager of own knowledge of the maintenance activity.
Observations	A lot of strategic information, collected in a handwritten form disaggregated in personal notes and notebooks, annotations on plans, not shared with the rest of the organization, which hinders the transmission and use of the knowledge by the rest of the organization.
Results of Proper Management of Knowledge in Maintenance Activity	Capture of the tacit strategic knowledge of operational maintenance technicians. Resolving critical failures in less time (especially non-cyclical ones). Reduction of operating manoeuvre times. Facilitate the change of area or personnel substitutions. Reduction of familiarization times for new personnel. Capture of information and transfer of subcontractor companies. Sharing the knowledge of employees that can be used by others who can detect new opportunities for improvement. Improved knowledge of the reliability of equipment and facilities. Improvement of knowledge for the detection and improvement of energy efficiency actions. Optimization of time, which again results in knowledge management and the reduction of maintenance costs. Improvement in self-learning in order to solve problems in the factory itself.

5. Conclusions

Industrial maintenance engineering requires a staff with deep technical knowledge, and who have a high component of tacit knowledge, acquired through years of work experience.

The main contributions of the research that are presented in this article, and that allow the extension of understanding on knowledge management in maintenance activities, are:

- The main facilitators/barriers detected are summarized based on the qualitative research carried out.
- The main strategic aspects of maintenance that can increase its efficiency are confirmed by adopting a knowledge management model.

- The high level of tacit knowledge used in this activity is confirmed, normally based on the high experience level required of the operators, and which requires high engagement times with new personnel.
- The knowledge directly impacts on, the resolution of critical actions and breakdowns in a shorter time, operational maneuver time reduction, and the improvement in knowledge for detecting and improving energy efficiency.

When addressing a knowledge management model for this activity, it is necessary to have an impact on the fundamental strategic maintenance activities confirmed by all the interviewed staff (reliability, maintainability, energy efficiency, and operation/exploitation), and which can improve the efficiency of all facilities.

From the survey of the perceptions of maintenance technicians (Figure 2), it is concluded that the perception that they have on their own knowledge (tacit) and the knowledge actually registered in the company (explicit), vary considerably, being approximately 50% recorded knowledge (explicit), as compared to their own knowledge (tacit). This is a problem when a workman leaves the company since their knowledge, with a high strategic component, is lost.

Participants in the study thought that the possibility of applying their knowledge to the organization's activities would stimulates their motivation to learn by themselves, learn new tools, and create new ways to carry out activities.

A greater use of informal meetings was suggested as a means of generating and transferring knowledge, especially among groups of operational technicians, with less of an organizational culture than the managers or maintenance managers.

A great use of informal knowledge transfer mechanisms was identified, which means that the information is found on "islands" within the organization itself.

The fundamental barriers located by this study were the limited availability of time to adequately document important actions, the cultural barriers, with a culture based on "own knowledge", not shared, especially among operational technicians, as well as achieving full involvement of the staff.

With this study, we have attempted to identify some key elements in order to improve the information and knowledge capture programs in the maintenance areas, according to the perception of the technicians who operate in these departments and facilitate its extension to all areas of the company.

This research through qualitative study should serve as a basis for future research, in order to design a knowledge management model applied to the industrial maintenance departments of companies, which reduces the gap between technicians' tacit knowledge compared to the knowledge registered in the company. It would also be suitable for making new studies with more companies from different countries in order to expand and confirm the data collected.

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