UNIVERSITÀ DEGLI STUDI DI FIRENZE

Dipartimento di Energetica
"Sergio Stecco"

Sezione Impianti e Tecnologie Industriali

XXIII Ciclo del Dottorato di Ricerca in

INGEGNERIA INDUSTRIALE E DELL'AFFIDABILITÀ

Integrated maintenance methodologies, approaches and tools along the plant life cycle: current level of implementation in the Italian companies and success elements for their penetration.

Tutor:

Ing. Gianni Bettini

Candidato:

Ing. Lorenzo Barni

Co-Tutor:

Ing. Filippo De Carlo

Coordinatore del corso:

Prof. Mario Tucci

Acknowledgments

This research project would not have been possible without the support of many people.
I wish to express my gratitude to my tutor, Ing. Gianni Bettini and to Professor Mario Tucci that offered invaluable assistance, support and guidance. Sincerest gratefulness is also due to Professor Martino Bandelloni who offered me the opportunity of this PhD course.
The author would also express his gratitude to the 50 companies involved in this project that showed great interest in this work and were very helpful during the interviews.
Many thanks to the members of "Sezione Impianti e Tecnologie Industriali", Professor Rinaldo Rinaldi, Ing. Mario Rapaccini, Ing. Romeo Bandinelli, Ing. Filippo Visintin and Ing. Filippo De Carlo, for their advices.
Many thanks also to Ing. Francesco Parretta for his support during the months spent at Dresser Italia.
Finally I wish to express my love and gratitude to Dragana, my parents and my friends, for their love through the duration of this PhD course.

Abstract

Over the past thirty years, maintenance has changed, perhaps more than any other management discipline. These changes are due to the increase in number and variety of the physical assets (plants, equipments and buildings) and to the much more complex designs. With the globalization of the marketplace and the coming of new competitors, many companies has begun to pay much more attention to the maintenance of their assets, in order to reduce operative costs and improve performance and competitiveness. This context has required first the development of new maintenance methodologies and techniques, then their computerization and automation by means of specific tools.

Today, several methodologies are available to study, model, assess and optimize asset reliability and the major challenge facing maintenance people is not only to learn what these methodologies are, but also to decide which are effective and which are not.

The scientific literature and the software market show that the characteristics of many maintenance tools, even if coming from different sources and heritages, seem to converge to an omni-comprehensive integrated solution. Maintenance experts generally agree on the fact that the current technological knowledge could make possible the computerization and integration of these maintenance methodologies (especially among the maintenance management and the maintenance engineering tools) and highlight the importance to carry out this integration along the plant life cycle.

Despite the scientific community and part of software vendors promote and research on this integration, the analysis of the state-of-the-art shows a lack of scientific studies that, on one hand, asses the real implementation and knowledge in companies of integrated maintenance solutions along the plant lifecycle and, on the other, identify which conditions must be present in the companies for this implementation and integration.

In order to close this research gap, this thesis aims at

1) assessing the current level of knowledge, implementation and automation in companies of:
   - integrated methodologies, approaches and tools for maintenance;
   - special purpose software;
   - information flows;
2) assessing if companies, that have implemented such integrated solutions for maintenance, use them along the lifecycle of their plants;
3) investigating the correlation among several company's structural variables and the maturity level of adoption of integrated methodologies, approaches and tools for maintenance along the plant lifecycle;
4) identifying the success elements and the barriers that promote or inhibit this integration;
5) assessing the potential interest of companies for a future implementation of integrated solutions.

The methodology adopted to answer these five points has been the survey based research.

This work, after a review of the scientific literature and the identification of the research gap (Chapter 1), describes in the Chapter 3 the development of the two questionnaires used for the survey: the first one has been developed to be submitted to companies that perform maintenance on their own plants, the second to companies that perform maintenance on third parties' plants (maintenance service companies).

The two questionnaires have been carried out basing on a reference model described on Chapter 2.

A first test of the questionnaires (Chapter 4), performed on a sample of 7 companies, highlighted difficulties in achieving a statistical significant number of maintenance service

companies, therefore it was decided to focus this work only on companies that perform maintenance on their own plants.
The definition of the sample interviewed is presented on Chapter 5. The two industrial sectors considered have been the paper sector and the chemical/pharmaceutical sector.
Chapter 6 deals with the first aim of this work and assess the current level of implementation, knowledge and automation of integrated solutions along the plant lifecycle.
Straight after, in Chapter 7, an assessment of the survey validity is carried out.
In Chapters 8, 9 and 10 the other four aims of this work are analyzed.
Chapter 11 summarizes the results obtained and highlights the main differences found between the two industrial sector studied.
In the Appendixes A and B are reported the two questionnaires used for this survey.

Index

1. Problem statement

As asserted by Moubray [1], "*over the past thirty years, maintenance has changed, perhaps more than any other management discipline*". Many factors have promoted these changes: the increase in the number and variety of physical assets (service plants, equipments and buildings), much more complex designs, new maintenance techniques and so on. With the globalization of the marketplace and the coming of new competitors, many Companies have begun to pay much more attention to the maintenance of their assets, to reduce operative costs and improve performance and competitiveness.

This context has required first the coming out of new maintenance methodologies and techniques, then their computerization and automation by means of specific tools.

Several methodologies are available in order to study, model, assess and optimize the asset reliability. Some of the better established are presented by Tucci M. [3] in his taxonomy: FMEA (Failure Mode and Effect Analysis), RBD (Reliability Block Diagram), RP (Reliability Prediction), FTA (Fault Tree Analysis), ETA (Event Tree Analysis), WA (Weibull Analysis) MC (Markov Chains), BN (Bayesian Networks) and so on.

Nowadays the major challenge facing maintenance people is not only to learn what these methodologies are, but also to decide which are worthwhile to be used and which are not, in order to improve asset performance and reduce their maintenance costs.

The Reliability Centered Maintenance (RCM) approach contains many of the above methodologies and represents one of the most effective way to evaluate and optimize maintenance policies. As defined by Moubray (2001), "*RCM is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context*". RCM approach determines the most realistic and optimized maintenance requirements of any physical asset to continue its stated operating condition.

Hossam Gabbar [2] highlights how many companies implement the RCM approach to formulate maintenance strategies for discrete manufacturing. However, he asserts also that the RCM is a time and effort consuming process if not automated and that normally it is employed without an adequate integration with the plant design and operational systems, essential to share and utilize plant design model and plant operational information (usually collected in the Computerized Maintenance Management Systems, CMMS). To overcome these limits Gabbar proposes an integrated system, where the RCM operates together with the CMMS. This integration focuses on the operational stage of the plant lifecycle, but the importance to extend it also to the design stage is well underlined.

Also Tucci [3] highlights the importance of this **integration along the plant lifecycle** and extends it not only to the RCM, but to all the maintenance activities and methodologies.

<u>This concept of integration along the plant lifecycle is the focus of this thesis</u>:

Integration because, quoting Tucci [3], "*in plant maintenance it's very important to understand the needs of the maintenance engineering processes, and how they integrate in the plant management activities. Especially the integration among CMMS (Computerized Maintenance Management Systems), accountable for the transactional aspect of maintenance, and the engineering tools, enabling a correct and efficient planning of the maintenance, should be taken into account.*"

Plant lifecycle because, as asserted by Barringer [18], the 85% of the total costs incurred during the operational life of the plant is determined by choices made during the design stage; therefore the adoption of an integrated maintenance process where the maintenance policies are decided during the design stage and then are updated during the operational phase, could be an important element to assure an high level of availability of the plant (and, therefore, the competitiveness of the company) [2, 3].
According with Bandinelli [10], the perspective of this work is the plant intended as a collection of several assets, therefore the plant lifecycle encompasses the lifecycles of all the assets within the system [11] (this concept will be treated in more detail later).

1.1 Theoretical background

The scientific literature and the software market show that the characteristics of many maintenance tools, even if coming from different sources and heritages, seem to converge to an omni-comprehensive integrated solution. Maintenance experts generally agree on the fact that the current technological knowledge could make possible the computerization and integration of these maintenance methodologies (especially among the maintenance management and the maintenance engineering tools) along the plant life cycle.
However the reality is far from this situation and the original purposes of the different software suites still constrain their effectiveness and their practical utilization. A survey, published by the *Plant maintenance resource center* [60] (carried out three times: in 2000, 2004 and 2007), on a sample of 105 companies of North America has revealed that almost the 82% of interviewees adopts a CMMS (the most used are SAP, MAXIMO and MP2), but the 23% of interviewees (often managers and maintenance supervisors) doesn't know why their company has implemented a CMMS. Moreover, the use of the CMMS is limited to cost accounting, spare part management and scheduling activity.
Another survey, still conducted by the *Plant Maintenance Resource Center* in the 2007 [61], concerns the implementation of RCM methodology. Based on a sample of only 39 interviewees, this survey shows that only the 64% of the interviewees has implemented RCM approaches. Of this part, only the 10% uses specialist RCM software package, while the 27% doesn't use any software. This result highlights how the use of computerized systems for the RCM analysis is not yet exploited.
The state of the art analysis has shown that so far the research and the software market have focused especially on the integration between RCM and CMMS. However, in the scientific literature, few are the models that propose integrated maintenance processes that encompass all the plant lifecycle.
Mostafa [64], in its proposal for the implementation of proactive maintenance strategies in the Egyptian glass companies, suggests a model of integration of the maintenance activities along the plant lifecycle: in his model the maintenance function receives information from the design phase, especially for what concerns the functional and structural characteristics of the plant. Such information are updated during the operation phase. The politic of maintenance recommended for this system is the predictive, by means vibration analysis. This study doesn't hint any sort of informatization of the various activities and doesn't consider the Maintenance Engineering function (fundamental to analyze the operational data and to achieve the optimization of the plant performances), both in the design phase and in the operational stage.
Experts are in agreement about the basic role that must have the CMMS: it is an indispensable tool for complex systems and when is need preventive maintenance. Un-

fortunately, as highlighted by the survey of the *Plant Maintenance Resource Center*, many companies don't exploit all the potential of CMMS.
What seems to be missing to the CMMS is a support for decision-making: the CMMS should be supported by a tool able to suggest the right maintenance policy. This support tool should answer questions like "How much routine maintenance should be done on this asset?", "How often should be replaced this part?", "How many parts of that component should be stocked? " etc.
Labib [17] suggests a mathematical decision-making tool based on fuzzy logic. It consists in a grid where are located the machine performance as a function of the frequency and duration of the failure. This model aims at reaching a low failure frequency and a low downtime, implementing proper actions. However, there isn't an integration between this model and the CMMS from the perspective of information exchange, so data entry must be performed manually.
Marquez [20] collects many different opinions of maintenance experts about the elements that should be included in the Maintenance Management function (to support the CMMS in the decision-making process). Among these, Wireman [65] and Pintelon [66]: the first one asserts that these elements should be: the introduction of preventive and proactive maintenance policies, a system for the work orders management, a proper technical training, the introduction of RCM approaches and the continuous improvement. Pintelon considers the structure of the Maintenance Management function divided into three blocks:

- management of the operations and of the design activities;
- planning and control, including the decisions that managers should take for what concern marketing, financial aspects, resources management and performance reports;
- statistical tools to calculate the frequency of breakdowns in the system.

Finally Marquez and Gupta propose a model of the maintenance management activity divided into three levels:

- <u>strategic:</u> assessment of the system criticality and transformation of the business priorities into maintenance priorities;
- <u>tactical:</u> proper allocation of resources to satisfy the maintenance plan;
- <u>operational:</u> ensuring that the maintenance activity is performed by skilled personnel, in the time planned, following the correct procedures and using appropriate instruments.

The operational level should be manage by the CMMS, while the tactical and strategic levels by the RCM system. Marquez and Gupta deal with another important aspect on their integration model: the Maintenance Engineering function. They assert that the same methodologies adopted for maintenance during the design phase, such as RCM, FMECA and HAZOP, should be used to assist the continuous system improvement process along the plant lifecycle. For the first time the Maintenance Engineering function is used both in the design phase and in the operational stage.
The work of Marquez and Gupta, however, "is limited" only to provide a basic supporting structure for this integration between maintenance management and maintenance engineering, composed by three primary pillars:

- The Organizational (or behavioral) Pillar: this pillar aims at attaining the best interface between different activity levels and between different functions within the organization, at attaining respect and care for all internal and external customers, and at attaining smoothness in inter-organizational relationships.

- The IT Pillar: this pillar allows managers, planners and production and maintenance personnel to have access to all equipment data and can transform this data into useful information, used to prioritize actions to carry out. This would be built as the company's Computerized Maintenance Management System (CMMS). The IT pillar also includes condition monitoring technologies.
- The Maintenance Engineering Methods Pillar: ensures the design of the maintenance process, the constant measurement and analysis of performance, the inter-functional involving and the consolidation and extension of results.

Marquez and Gupta don't explain how integrate these pillars along the plant lifecycle, or better, how to integrate all the management and engineering tools, methodology and approaches that "populate" each pillar. For this reason, in the next section is presented the review of all scientific work that deal with the information exchange between the various maintenance tools.

1.1.1 Information flows between maintenance tools: literature review

As seen above, many works found in the scientific literature show how the CMMS requires a decision-making supporting tool in order to assess the appropriate maintenance policies and activities to perform. For this role some maintenance expert is oriented towards the use of the RCM assisted by other methodologies of the maintenance engineering such as FTA, FMEA, HAZOP, ETA and others. Consequence of this is the fact that the RCM, the CMMS and all the maintenance engineering tools involved in this integration process need a large number of data, possibly exchanged in real time.

While for the maintenance engineering tools already exist on the market many special purpose software that integrate different maintenance methodologies, for what concerns the integration between CMMS and RCM realities on the software market are few and in strong development. A software market survey in 2009 discovered two solution (although probably not unique):

- *RCMO*, a new integrated RCM solution co-developed by SAP and Meridium. RCMO integrates closely the recommendations from the Meridium RCM into the SAP CMMS, in order to support the CMMS in the decisions to be taken and in optimizing the management of maintenance.
- *AWB*, a product of Isograph, that integrates AvSim+ (the Availability Simulation Software of Isograph) and RCMCost (the Reliability Centered Maintenance software of Isograph), including a Lifecycle Cost Analysis module and a Weibull Analysis software. AWB adopts also a SAP interface in order to allow the data exchange between AWB and SAP.

The scientific works found by the author that treat this issues (integration between RCM, CMMS, Maintenance Engineering methodologies and related information flow) can be divided into two categories:

- the first one considers the information exchange into a CMMS and RCM integrated system;
- the other one considers the information exchanged between the CMMS and software for predictive maintenance (the so-called PdM).

Before analyze in depth this issue, it must be said that the software market offers several packages for CMMS and RCM and therefore is almost impossible that these tools can communicate with each other because they use different languages. It's essential to highlight the difference between data and information:

- data can be transmitted, but not necessarily are comprehended by the software;
- information are data that are made comprehensible for certain software.

The highest level reachable could be a standardization of information so that all programs can interface with each other.

Integration between RCM and CMMS

Part of the scientific literature focuses on identifying the data in CMMS that can be useful to the RCM, highlighting the type of database that can promote the integration [4,7,8, 9,17]. Another part of the scientific literature focuses more on the RCM role in establishing maintenance strategies to transmit to the CMMS [2].

Picknell and Steel [9] have studied how the RCM can be supported by a CMMS: they describe how should be designed a CMMS able to collect data and transform them into information to be processed by the RCM. The database of a CMMS should be multidimensional and should contain all the information about the asset (which may be a machine or a component) and its location on the plant.

Once data are collected, it is not necessary that the RCM analyzes each asset, but only those critical. The RCM assigns a weight to each critical asset, in order to establish priorities for action:

1. first are considered those assets critical for the safety of people and environment;
2. then those that cause a loss of production;
3. finally, those assets that have high maintenance costs, low MTBF and long downtimes.

Picknell and Steel analyze the seven questions of RCM assessing which information may be provided by the CMMS in order to answer them:

- As regards the definition of the functions and of the performance standards, a CMMS should enable the user to insert into it the characteristics of the machines and their locations. These specifications should include operational characteristics and performance standard values as temperature and pressure.
- Once identified the failure modes using the RCM, it should be possible to insert these data into the CMMS so that they are associated with the machine and its position through a fault code. These codes will form the historical database of the machine, useful for eventual statistical analysis.
- The CMMS should also be used to investigate the failure causes.

Another study of integration between the RCM and the CMMS has been carried out by Huo [4]. She asserts that, to estimate the priorities for action through the RCM, can be used several failure indicators contained into the CMMS. For instance, to decide the priorities for action basing on the maintenance costs, it is sufficient to control the work order cost summary report, grouped by asset type and ranked in order of increasing cost.

In other words, Huo asserts that, using determinate reports obtained from CMMS, it is possible to establish the priorities for action. This can be done, as represented in the table below, for the maintenance costs, for the emergency work, for the high frequency of failure and for the longest downtimes.

Table 1: possible reports used to establish the priorities for action

Failure indicators	**CMMS resource**
High maintenance costs	Work order cost summary report
Most emergency work	Work order analysis graph
High frequency of failure	MTBF report
Highest amount of downtime	Work order analysis graph

Many researchers and also Huo underline the critical contribute of the CMMS to the RCM: all the relevant information needed by the RCM should be collected into the CMMS, in particular those related to the assets (data and characteristics of all the assets to maintain) and to the work orders (maintenance interventions, hours of maintenance work, downtime duration, etc).
All these data are used to reconstruct the asset life history, which is the basis of the RCM.
In order to maximize the potential of the CMMS, Huo suggests the use of standard procedures. These are based on two main points:

1. No intervention should be carried out without a work order;
2. All the information must be collected into the CMMS.

These procedures are called SOP: Standard Operating Procedures.
Huo focuses her attention exclusively on the role of the CMMS as support of the RCM, without mentioning the fact that a reciprocal information exchange could be a big benefit for both (the CMMS, in fact, is not able to decide the appropriate maintenance policy).

The model most similar to the reference model adopted in this work and showed in the Figure 1 has been developed by Gabbar [2]. He suggests a model of integration between RCM and CMMS that will be treated in more detail later.

Integration between CMMS and software for predictive maintenance (PdM)
Another type of integration found in the scientific literature is that between CMMS and software for Predictive Maintenance, which is widely treated by D. A. Lofall [67].
The Predictive Maintenance is defined by the UNI 10147 as follows:
"*Predictive Maintenance is a Preventive Maintenance carried out after the detection and measurement of one or more parameters and after the extrapolation, in accordance with appropriate models, of the remaining time before failure*"
The CMMS is an important tool for the maintenance management, but it cannot monitor in real time all the asset parameters. This duty is performed by the predictive maintenance tools (PdM) that excel in monitoring, but are lacking in maintenance management.
Unlike the integration between CMMS and RCM, which is still at an early stage of development, the integration between CMMS and PdM is in great expansion. Also the transfer of information is more developed (for example for what concerns sensors and portable devices used by the operators that make faster the communications between man and machine).
Concerning the data exchange with the CMMS, the method used is the passive data transfer: the software for predictive maintenance send the data received from sensors to a *Plant Data Warehouse* periodically monitored by the CMMS that imports the data into its database. Of course, it is necessary that the two software can communicate with each other in order to understand and process the data. To achieve an immediate access to the information, CMMS and PdM must be fully integrated.
The first step towards a full integration is setting up a way for CMMS and PdM to communicate. Quoting Lofall "*this is analogous to help a Frenchman and a German to communicate when neither understands the other's language. In the case of CMMS and PdM technologies (two systems that cannot initially understand each other's language), the first step is setting up consistent data in each system that will allow them to communicate using a common base of information*". For example, it is essential that what is into PdM exists even in the CMMS and is called with the same name.
Then, should be exist a system of data cross-references between all the sensors of the PdM system and the modules of the CMMS that associates readings in one system with

readings in the other. For example, an alarm should automatically trigger a pre-defined work order.

Finally, the full integration is obtained allowing the PdM programs to read and write the CMMS database (and vice-versa). Today, CMMS databases with open architecture such as ISAM (External Indexed Sequential Access Method; MS Access, Dbase, FoxPro, Btrieve, Paradox and others) or ODBC (Open Database Connectivity; Microsoft SQL Server, Sybase SQL, Oracle and others) can be read from and written to by PdM programs with ISAM and ODBC capabilities.

Nowadays this area is very developed, with a market that offers many database able to read and process data and transform it into information.

1.1.2 Research projects and software suites concerning integration

As told before, the first step towards a full integration is enabling the various maintenance tools to communicate with each other.

Solutions found in the scientific literature follow two different ways:

- The creation of Plant Data Warehouse able to collect data coming from many different software that use different languages. This databases are developed using the SQL or XML languages.
- A commercial alliance between two software vendors that operate in different sectors in order to integrate their tools.
- A commercial alliance between many software vendors that operate in different sectors, in order to create standards for a better integration of the various software tools.

The Plant Data Warehouse

The market offers a large number of software packages both for the CMMS and the maintenance engineering tools. Only for the CMMS the software proposed are hundreds and is difficult to create an interface compatible with everyone. In this case, the general idea is to work with those software that are more adopted by companies.

All the most famous CMMS (such as SAP, MAXIMO, MP2) have developed a Plant Data Warehouse for processing and transforming data into information that can be read and understand by different software.

SAP, for instance, uses its Data Warehouse (Business Intelligence) which allows it to process the data collected from the field. MAXIMO and MP2 are both interfaced with the Oracle database.

These Data Warehouse, however, are mainly used in the exchange of data between the field and the CMMS, and are not used to exchange data with the maintenance engineering software.

Commercial alliance of software vendors for the integration between CMMS and RCM

Some companies have formed a commercial alliance to integrate their software tools. Concerning the integration between the RCM and the CMMS, one interesting solution is RCMO, a new integrated RCM solution co-developed by SAP and Meridium. RCMO integrates closely the recommendations from the Meridium RCM into the SAP CMMS, in order to support the CMMS in the decisions to be taken and in optimizing the management of maintenance.

RCMO defines the maintenance policies basing on the principles of the RCM, integrates the indications of the RCM analysis in the planning of the maintenance activities of SAP

and reviews the impact of the maintenance strategies basing on the plant performance, to achieve a continuous improvement.
Through the interface between the two software, RCMO uses the information provided by SAP on the plant *equipment tree* and analyzes the failure modes and effects, that are the basis for the definition, by the RCM, of the proper maintenance policy to adopt. Once the policies have been approved, they are sent to SAP to proceed with the maintenance management. Once the planned maintenance activities are performed, the historical archives of the plant or of the component are updated. These archives are sent from SAP to RCMO that performs a FMECA analysis, reviews the maintenance strategies and, if necessary, develops new maintenance policies. This procedure is a cycle that assures the continuous improvement of the plant performance.

The MIMOSA project and the Open Operations & Maintenance
The acronym MIMOSA stands for *Machinery Information Management Open Systems Alliance*. MIMOSA is an alliance of Operations & Maintenance (O&M) solution providers and end-user companies who are focused on developing consensus-driven open data standards to enable Open Standards-based O&M Interoperability.
Together with the OPC Foundation and ISA-SP95 has created an alliance called the *Open Operations & Maintenance*, oriented to facilitate the integration, the diagnostics, the prognostic, the monitoring and the maintenance of all the applications of a company. Each organization is responsible for a part of the project:

- OPC is a foundation which has created standards for the information exchange between the control systems and the production applications associated, for example between portable monitoring devices and the supervisor SCADA system.
- ISA-95 stands for *Instrumentation Systems & Automation Society* and it creates standards for the integration between the company and the production management system.

The Alliance *Open Operations & Maintenance* deals only with the operational phase of the plant lifecycle, focusing exclusively on the predictive maintenance.

1.2 Research questions and adopted methodology

From the above results and argumentations a consideration emerges: the scientific community has provided a huge amount of sound methodologies, on one hand, and the software market has developed and offers (or at least advertises) powerful tools that implement such methodologies, on the other hand. Meanwhile, many companies have adopted maintenance engineering approaches (such as the RCM) to solve maintenance problems and, struggling to obtain a cost effective maintenance and to optimally manage these processes, are using CMMS solutions.
Despite the scientific community and part of software vendors promote and research on the integration of maintenance processes, methodologies and tools along the plant lifecycle, the analysis of the state-of-the-art shows a lack of scientific studies that, on one hand, asses the real implementation and knowledge in companies of integrated maintenance solutions along the lifecycle of their plants and, on the other, identify which conditions must be present in the companies for their implementation and integration.
In order to close the described research gap, this work aims at answering these two research questions:

1) **which is the current level of knowledge, implementation and automation of maintenance approaches, methodologies and tools, integrated along the plant lifecycle?**
2) **which are the barriers and the success elements for their penetration**?

The methodology adopted to answer the two research question is the survey based research.

These two research questions have been split up into five aims:

1) assess the current level of knowledge, implementation and automation in companies of:
   - ✓ integrated methodologies, approaches and tools for maintenance;
   - ✓ special purpose software;
   - ✓ information flows;
2) assess if companies, that have implemented such integrated solutions for maintenance, use them along the lifecycle of their production plant;
3) investigate the correlation among several company's structural variables and the maturity level of adoption of integrated methodologies, approaches and tools for maintenance along the plant lifecycle;
4) identify the success elements and the barriers that promote or inhibit this integration;
5) assess the potential interest of companies for a future implementation of integrated solutions.

According to the classification of Forza C. [12], the survey carried out to pursue the five aims is a descriptive type. A descriptive survey research is aimed at understanding the relevance of a certain phenomenon and describing the distribution of the phenomenon in a population. Its primary aim is not theory development, even though through the facts described it can provide useful hints both for theory building and for theory refinement [13, 14, 15].

The survey has been submitted to 50 companies that performs maintenance on their own plants and has been designed referring to a conceptual model proposed by Tucci and Bettini [3] and revisited by Barni and Tucci [16].

2. *Description of the reference model*

The reference model spreads the maintenance function over three layers in parallel to the plant lifecycle (Figure 1):

- The lowest layer is represented by the maintenance activities during the plant operation. The monitoring, the control and the in-field acquisition of data is ensured by PLCs, SCADA systems and process computers.
- The second layer is represented by the maintenance management: planning, programming, scheduling and accounting of maintenance. These tasks are performed by CMMS.
- The third layer is represented by the maintenance engineering (the tools and models considered are the reliability prediction, the Fault Tree Analysis, the Event Tree Analysis, the support logistics modelling, the Failure Mode and Effect Criticality Analysis, the Reliability Block Diagram, the HAZard and OPerability analysis and the RCM).

Figure 1: maintenance activities along the plant lifecycle

In this model the plant lifecycle has been intended in accordance with the traditional system lifecycle [19] and is divided into five main phases [10]:

1) plant design (conceptual basic design and detailed design),
2) plant construction (construction, test and handover),
3) plant operation,
4) plant revamping,
5) plant dismantling.

For each stage of the plant lifecycle, the model shows the information flow that the maintenance engineering and management activities and all the methodologies and techniques exchange among them in an integrated system.
According with Bandinelli and Tucci [10], the perspective of this work is the plant intended as a collection of several assets, therefore the plant lifecycle encompasses the lifecycles of all assets within the system [11].
In accordance with the model of Schuman and Brent [11], during the conceptual basic design of the plant the needs for assets are identified, then, during the detailed plant design, conceptual and preliminary design of assets take place. During the operational stage of the plant, the several assets can have different MOL or EOL, becoming worn and needing to be replaced, but it is rare that the whole plant is retired [11]. Therefore, a revamping is performed.
This synchronization of most of the plant lifecycle phases deeply affects information flows.
The reference model was developed according with Morel, Suhner [21] and Marquez, Gupta [20] that propose an "*holistic framework for managing the maintenance function heretofore inundated by myriad tools, trappings, practices, and prescriptions*". This holistic approach in maintenance should be able to give the correct information at the right place at the right time.
As asserted by Marquez and Gupta, today "*a myriad considerations, data, policies, techniques and tools affect the effective execution of maintenance, particularly in a modern technologically endowed factory. In such instances, an integrated, rather than the conventional 'silo' style approach to maintenance management would play a pivotal role. However, much difficulty in the practice of maintenance management arises from the mixup between the actions and the tools designed to enable them. This issue often remains unresolved by practitioners and unaddressed by researchers*".
As seen before in the section 1.1, to overcome this problem, Marquez and Gupta suggest to move along two lines:

- the first line concerns the definition of the essential elements of the maintenance function from a <u>strategic</u> (transformation of business priorities into maintenance priorities), <u>tactical</u> (actions to properly allocate resources - skills, materials, test equipment, etc. - to satisfy the maintenance plan; as a result, a detailed program would materialize with all tasks specified and resources assigned) and <u>operational point of view</u> (execution of maintenance by skilled technicians).
- the second line concerns the definition of 3 basic pillars. In fact, the three courses of action above described (strategic, tactical and operational) and the related processes are clearly interrelated. To simplify the maintenance management process in an organization (at the three mentioned levels), a basic supporting structure is needed. This structure consists, as explained by Marquez and Gupta [20], in three primary pillars:
  - ✓ The Organizational (or behavioral) Pillar;
  - ✓ The IT Pillar;
  - ✓ The Maintenance Engineering Methods Pillar.

The reference model in Figure 1, adopted to carry out the questionnaires of the survey, shows a possible solution of integration between all the methodologies and tools of Maintenance Engineering and Maintenance Management. This model, focused on Maintenance Engineering and on its IT implementation, doesn't take into account the organizational aspect of the maintenance activity. Therefore it has been considered fundamental to adopt the basic supporting structure of three pillars suggested by Marquez and Gupta (especially for what concerns the organizational pillar).

The model presented by Hossam Gabbar [2] has been very important for the design of the model of Figure 1. Gabbar suggests a model of improved RCM process, integrated with the CMMS for the operational stage of the plant life cycle. His model includes four main processes: the plant design environment, the RCM process, the CMMS and the operational system. In Gabbar's model, the RCM component is an expert system that decides the optimum maintenance strategies and calculates the different quantitative parameters of the maintenance tasks. The CMMS is used during the operational stage to manage and implement the maintenance strategies extracting asset information together with their functions from the design environment (i.e. from the design model). The RCM utilizes the asset information together with the design and operational data/knowledge to perform asset and failure assessments and to build the failure and risk data/knowledge bases. Starting from the design stage, the RCM module is invoked to suggest the preliminary optimized maintenance strategies for the selected assets based on the process design model. Gabbar defines "OO model" the prime output of the plant design environment, which includes the plant static (structure and topology), behavior, and function views. Plant asset information are extracted from the plant static model contained into the CMMS and are passed to the RCM process. Failure model is developed within the plant design using HAZOP, FTA, and FMECA techniques, and transferred into failure and risk data.
Gabbar highlights the importance of the design stage and identifies it as the stage where are initially decided the maintenance strategies that will be tuned during the operational stage by the RCM using feedback information from the operational systems and the reliability data.
The integration with the design systems, suggested by Gabbar, is intended only as source of data to be collected into CMMS that will be used by the RCM process during the plant operational phase. There isn't an integration between the maintenance engineering tools and the CAx systems used during the design stage and there isn't an analysis of feedback information for a possible revamping of the plant.

According with Gabbar, in the reference model adopted (see Figure 1), <u>during the design stage</u> the maintenance strategies are initially decided by the RCM (RCMD) and the failure model is developed using HAZOP, FTA, FMECA (related with the Reliability Prediction that gives the failure rate of each component of the plant). But, unlike Gabbar, in this model CAx systems (DDD) receive from maintenance engineering activities (MED) suggestions for modifications in order to improve the reliability.
Dealing with the <u>operational stage</u>, this model presents many point in commons with the Gabbar's one:

- the RCM tunes the maintenance strategies decided during the design stage, using plant information collected by the CMMS during the operational stage (MMO) and, in collaboration with the other maintenance engineering tools (MEO), performs asset and failure assessments and builds the failure and risk data/knowledge bases.
- The CAx systems (DDD) provide to the CMMS (MMO) and to the maintenance engineering tools (MEO) the design documentation updated with the improvements applied during the plant lifecycle (the design book as built).
- The Reliability Prediction activity updates the failure rates using data coming from operational systems (SCADA) and CMMS and provides them to maintenance engineering tools.
- The CMMS system collects on one hand the plant operational data coming from SCADA systems and on the other hand records all the maintenance tasks, inspections and diagnostics. With some basic processing it provides them to maintenance

engineering tools and receives back the information to manage and implement the maintenance strategies.

Re-design is another important stage of the plant lifecycle, closely related with CAx systems. During this stage, limited or global modifications to the plant are carried out. Elements for such modifications are suggested to CAx systems by the RCM. The output data is the Design Book updated.

2.1 Definition of the areas of the reference model

The reference model presents all the maintenance activities (the areas of the model) integrated along the plant life cycle.

As told before, this model spreads the maintenance function over three layers in parallel to the plant lifecycle:

- The lowest layer is represented by the maintenance activities during the plant operation.
- The second layer is represented by the maintenance management.
- The third layer is represented by the maintenance engineering.

Before explaining what these areas are, especially those of the third layer, it's better to give an introduction to the R&ME (Reliability & Maintenance Engineering).

Quoting Tucci [3]: "*R&ME consists of the systematic application of engineering principles and techniques throughout a product lifecycle and thus it is an essential component of a good Product Lifecycle Management. The role of R&ME aims at different goals, according to the sector of the product*". Tucci refers to the product in a large sense: from a product as a mass market item to a product more complex as an industrial asset or a complete industrial plant.

In the process industry, the R&ME techniques are implemented to avoid remarkable failures. In this case failure effects can are evaluated as costs (an "economical risk level" is defined). This approach is the most used in manufacturing industries where availability is much more important than reliability and cost is the main performance to evaluate.

Therefore, the role of the RE (Reliability Engineering) is to reduce potential failures. It's very difficult to identify all the potential failures of a product during the design stage, therefore the RE identifies only the most likely.

The role of the ME (Maintenance Engineering) is to identify appropriate actions to mitigate the effect of the possible failures identified by the RE. These actions can be actions of corrective, preventive or predictive maintenance.

As asserted by Tucci [3] "*one of the main factors concurring to the choice of appropriate analysis is the phase of the plant lifecycle*". Two are the main phases of a plant lifecycle: design phase and operational phase.

As told before, quoting Barringer [18], during the design phase the 85% all of the costs of the lifecycle are fixed. In the design phase it is possible to anticipate the effects of design changes and corrections: "*a preventive evaluation is possible, basing on literature data (data banks) or similar cases and modeling the use of components with different reliability level, assembled in different configurations, served with different maintenance policies. Combining this data with cost information, cost-effectiveness of products is estimated*".

However, even if a product has a robust design, during the operational phase the performance of the product may be unsatisfactory because preventive evaluations are affected by uncertainties deriving from data banks (a-priori knowledge) and from conditions encountered in the operational phase different from those considered in the design phase. So, tak-

ing into account the field data (a-posteriors knowledge), new analysis can be performed in order to validate or modify components, system configurations or maintenance policy.
Changes to a design are orders of magnitude less expensive in the early stages of a design phase, rather than once the product is manufactured and in service.
After this brief introduction, as told before, the reference model used to design the questionnaire aims at the creation of IT and Maintenance Engineering Methods pillars (of the model of Marquez and Gupta [20]). In this model the R&ME techniques are integrated with the maintenance management process and the activities performed during the plant life-cycle.
The description of all the elements of the model is essential for a proper interpretation and comprehension of the choices made during the design of questionnaires.
In the figure 1 is shown the complete model, in the figures 2 and 3 are shown in more detail the Maintenance Engineering areas of the operational and design stages (MEO and MED). These figures highlight the R&ME techniques considered and their reciprocal relationships.

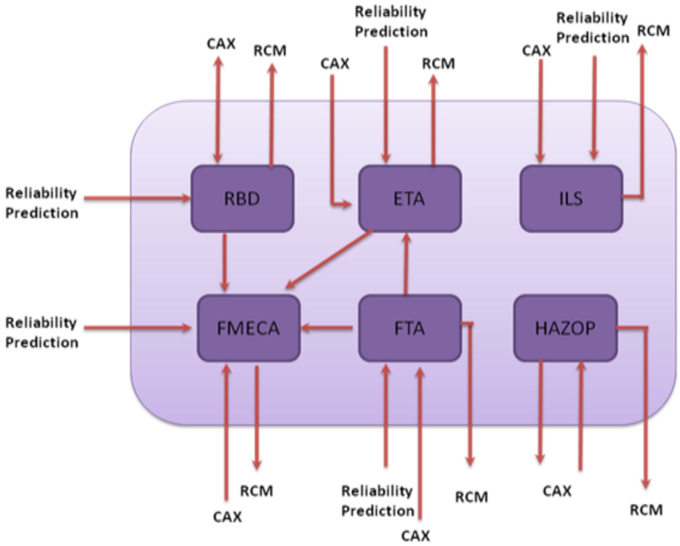


Figure 2: MED area

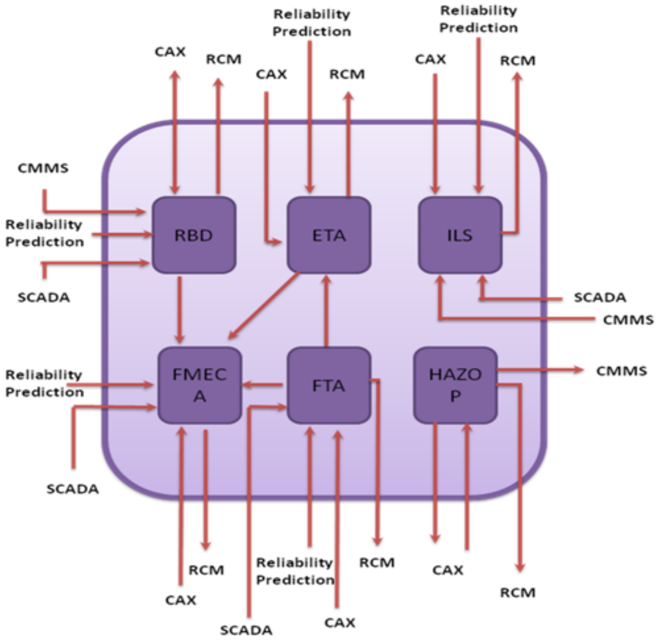


Figure 3: MEO area

The R&ME techniques adopted in the model are briefly presented below.

2.1.1 Reliability Prediction (RPD/O)

As defined by Tucci in his taxonomy, [3] "*reliability prediction (RP) is a process that, starting from the knowledge of some reliability model for the components of a system, and taking into account the configurations and relationships among the components, leads to an estimate of several typical functions, as reliability, MTBF or MTTF, availability for repairable systems and so on*".

The utility of the Reliability Prediction is particularly evident during the design process of a product/plant: it can be used, for instance, to verify if a certain design satisfies the RAMS requirements or to take decisions in the trade-off between costs and performances. Moreover, RP is the starting point for several methodologies such as LCC, RCM, ILS.

This process investigates and assesses the reliability of each component of a system, as a function of many variables (time, condition of use, demanded performances, environment of use and duty cycle). As highlighted by Tucci, important sources of information for such difficult task may be:

a) data banks and standards;
b) data provided by the vendors of the components (seldom provided);
c) experience and field return on previous designs and productions;
d) field tests (very expensive).

Because the reliability depends on many factors, a good explanation of its variability should be based on a deep knowledge of the physics beyond it (fatigue, wear-out, vibrations, shocks, creep, and so on), or on the observation of samples of several thousand elements of the same typology under controlled use. Several data banks exist, but their poor concordance, especially in the mechanical components and machinery, was frequently observed. In the electronic components domain, more accurate models are available for the most utilized technologies.

2.1.2 Maintenance Engineering (MED/MEO)

This area deals with different Maintenance Engineering techniques, such as:

Reliability Block Diagram (RBD)

An overall system reliability prediction can be performed analyzing the reliability of all the components that compose the whole system. The Reliability Block Diagram (RBD) is a technique for the assessment of the reliability of a system, starting from the knowledge of the behavior and reliability of its components. Using block diagrams to show network relationships, RBD displays how components and sub-system failures combine with each other to cause a system failure.

The blocks of the RBD diagram can represent the physical component with certain functions or the functions (or sub-functions) themselves that contribute to the operation of the whole system. For each block, whether it is representative of a physical item or it corresponds to a sub-function of the system, it is possible to specify the distributions of the failure times, of the maintenance times and of the logistic times.

Fault Tree Analysis (FTA)

Differently from the RBD model, which consider the state of the system elements as functioning or faulty, the Fault Tree Analysis (FTA) is based on the failure events. Moreover, RBD only considers hardware malfunctioning while FTA may consider every kind of undesired event, as software failure, human errors and so on.

The Fault Tree Analysis is a technique by which the conditions and the factors that can contribute to a specified undesired event are identified, organized in a logical manner and represented pictorially.
Starting with the undesired (top) event, the possible causes of that event are identified at the next lower levels. If each of those contributors can produce the top event alone an OR gate is used; if all the contributors must act to result in the top event an AND gate is used. Then continue to the next levels.
The probability of the top event is calculated using the Boolean algebra and the probability theory, taking into account the problems arising from the common causes of failure in the bottom events. But, definitely more interesting is the derivation of the Minimal Cut Sets (MCS). MCS represent the set of events that are necessary and sufficient to generate the considered top event (failure). Besides allowing another way of calculating the probability of the top event, they give a deeper insight to the reliability structure of the system, allowing for the mitigation of the more critical bottom events.
The FTA has been used for the first time in 1962 for the nuclear stations. A more detailed study of this methodology can be found in NASA Office for Safety and Mission Assurance [23] and in USA Nuclear Regulatory Commission [24].
Thank to its versatility, this technique can be used both during the design phase (whose an interesting investigation is provided by Krasic [25]), both during the operational phase (in this case an example of integration with the RCM approach is provided by Masdal S.I. and Bye R.[26]).
Although the principles used in the construction of fault trees for different phases of the plant lifecycle are the same, there are some differences in the strategies used, in the aims and in the level of detail considered, just due to the peculiarities of each stage of the life of a system.
In the construction of a fault tree dedicated to the design phase, the detailed specifications or drawings are not available; often is present only a macro description of the basic functions and interfaces. In this case the role of the FTA could be the determination of the maximum probability of occurrence of a top event. The FTA performed on an operating system, instead, should be characterized by a greater availability of information. In this case its aim should be to improve the system and/or diagnose any critical aspect.

Event Tree Analysis (ETA)
The Event Tree Analysis is a graphic representation that starts with an Initial Event (top event) and shows the possible accidental situations that may arise as result of the Top Event.
Quoting Tucci [3], there is a sensible difference between ETA and FTA: the Fault Tree Analysis is performed to investigate the possible causes that generate the Top Event, "*Event Tree Analysis is usually performed at a more general level on the system under study, compared to the fault tree analysis. The Event Tree Analysis studies the positive and negative effects of the safety systems produced as a consequence of a dangerous initiating event (i.e. the Top Event of the FTA), in order to be able to enumerate the possible scenarios and the consequences of the initiating event with respect to the behavior of the system*".
Often the Software houses offer solutions of ETA integrated with FTA, being the Top Event of a FTA the initiating event of an ETA.

Failure Mode and Effect Analysis (FMEA/FMECA)

Failure Mode and Effect Analysis (FMEA) is a procedure for analysis of potential failure modes within a system and of the consequences arising from those failures. FMEA is an inductive process, as ETA, but differently from ETA, which has an initiating event with many possible consequences, FMEA has several possible component failures which affect the same system with a negative final effect.

To start it is necessary to describe the system and its function. Then, a Functional Block Diagram (FBD) of the system needs to be created. This diagram gives an overview of the major components of the system and how they are related.

At this point, for each component, the FMEA lists:

- all the possible failure modes, and for each:
- all the possible causes
- all possible effects
- all the possible controls to prevent or detect the specific failure mode.

For each combination of failure mode – cause, FMEA evaluates three factors:

- Probability of occurrence of the failure: each failure mode is given an Occurrence Ranking (O), from 1 (low probability of occurrence) to 10 (very high probability of occurrence). Actions need to be determined if the occurrence is high.
- Severity of the effect: to each effect is given a Severity Number (S) from 1 (no danger) to 10 (critical; a severity rating of 9 or 10 is generally reserved for those effects which cause injury to the user). This number helps to prioritize the failure modes and their effects. If the severity of an effect is 9 or 10, actions must be taken in order to eliminate the failure mode, if possible, or protect the user from the effect.
- Possibility of detection of the failure by controls: each combination from the previous 2 steps receives a Detection Number (D), from 1 to 10. This number identify the ability of planned tests and inspections to detect the failure modes in time. The assigned detection number measures the risk that the failure is not detected. A high detection number indicates that this risk is very high.

There are tables published by AIAG, VDA, ANFIA, SAE, etc, that provide values of these factors for many failure modes and effects.

After ranking the severity, occurrence and detectability, for each combination failure – effect it is calculated the Risk Priority Number (RPN), multiplying the three ranks: $RPN = S \times O \times D$.

To the failure modes with the highest RPN should be given the highest priority for corrective action. This means that not necessary the first failure mode to treat is that with the highest severity number, but could be for example the less detectable (or a combination).

Failure mode, effects, and criticality analysis (FMECA) is an extension of the failure mode and effects analysis (FMEA) that include a criticality analysis, used to chart the probability of failure modes related to the severity of their consequences.

Despite its large use and flexibility, FMEA has some drawbacks, as it doesn't consider the redundancy of elements, multiple component failures or sequence dependent failures.

ILS

Integrated Logistic Support (ILS) is a methodology that integrates the design of a complex system with the planning of its support and maintenance. It's a methodology developed in the military environment, to regulate the supply of weapon systems, a peculiar product with extremely long life, high mission criticality and relevant maintenance costs.

In general, ILS plans and directs the identification and development of logistics support and system requirements for military systems, with the goal of creating systems that last long and require few supports, thereby reducing costs and increasing return on investments. The impact of ILS is often measured in terms of metrics such as reliability, availability, maintainability and testability (RAMT), and sometimes System Safety (RAMS).

2.1.3 Reliability Centered Maintenance (RCMO/RCMD)

The Reliability Centered Maintenance (RCM) is a process intended to determine the most realistic and optimized maintenance requirements of any physical asset to continue its stated operating condition. Reliability Centered Maintenance (RCM) is a methodology used to choose maintenance policies basing on reliability prediction analysis.

The RCM approach encompasses several methodologies and techniques, as the Reliability Prediction, the RBD and the FMECA, in order to maximize the plant operational availability, safety and the production quality. The RCM process uses failure mode and effects analysis (FMEA) to systematically identify the plant failure modes, and assist in selecting the appropriate maintenance strategy for each of them, taking into account the possible redundancy of critical items, the spare part requirements and stock policies, and the maintenance crew manning level.

The RCM process is defined by the technical standard SAE JA1011 Evaluation Criteria for RCM Processes [27], which sets out the minimum criteria that any process should meet before it can be called RCM. The RCM answers the 7 questions below:

1. What is the item supposed to do and its associated performance standards?
2. In what ways can it fail to provide the required functions?
3. What are the events that cause each failure?
4. What happens when each failure occurs?
5. In what way does each failure matter?
6. What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
7. What must be done if a suitable preventive task cannot be found?

Through the RCM it is possible to introduce a complete maintenance regime, where the maintenance process is used to maintain the functions that an user may require to the plant in a defined operating context. The RCM enables the plant stakeholders to monitor, assess, predict and better understand their assets. This is embodied in the initial part of the RCM process which consists in the identification of the operating context of the plant, and in the definition of a Failure Mode Effects and Criticality Analysis (FMECA). The second part of the RCM approach helps to determine the appropriate maintenance tasks for the identified failure modes in the FMECA. Once the logic is complete for all elements in the FMECA, maintenance plans are defined and rationalized. RCM is continuously performed during the operational stage of the plant, where the effectiveness of the maintenance is kept under constant review and adjusted in light of the experience gained.

Reliability Centered Maintenance can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to define a routine maintenance program composed of cost-effective tasks that preserve important functions.

The important functions to preserve with routine maintenance are identified, their dominant failure modes and causes determined and the consequences of failure ascertained. Levels of

criticality are assigned to the consequences of failure. Some functions are not critical and are left to "run to failure" while other functions must be preserved at all cost. When the risk of the failures is very high, RCM encourages (and sometimes mandates) the user to consider changing something which will reduce the risk to a tolerable level.
RCM emphasizes the use of Predictive maintenance (PdM) techniques in addition to traditional preventive measures.

2.1.4 Detailed Design (DDD/DDR)

This area is strictly related to the Computer Aided Design (CAD) tools. CAD allows the designer to transfer projects from the "drawing board" to the PC, benefiting of the computer graphics technology. Through the computer-aided design tools, the designs are recorded in the computer mass memory, together with the list of all components that make up the system. The documentation concerning the system design, from the drawings to the lay-out information, from the functional to the structural characteristics, are collected in the *design book*. There are differences between the design book developed during the design phase and the design book updated during the operational phase or during a revamping (called *design book as built*). The design book as built, in fact, contains all the changes made after the manifestation of problems arose during the construction phase.

2.1.5 Process Control Systems (SIO)

This area is related to the supervision and inspection systems that allow the systematic plant data collection and facilitate the decision processes and the consequent allocation of resources (based, thank to these systems, on objective evidences). It is the only reliable way to assess the responsiveness and effectiveness of the choices made during the design phase or a revamping. The data acquisition and data management is strongly linked to the SCADA (Supervisory Control and Data Acquisition) systems, born as systems of data collection and control without active control of operations.
In this recent years there has been an evolution of these systems towards an active control capability.

2.1.6 Maintenance Management System (MMO)

This area is represented by the Maintenance Management System. The definition of a Maintenance Management System can be found in the UNI 10584/97: "*the set of rules, procedures and tools to collect and process all the information necessary for the management of maintenance activities and for the monitoring of the plant operations*". Usually, the Maintenance Management System is divided into four components:

- *environment*: consisting of the general information about the company and its physical assets such as machinery and equipment;
- *maintenance management*: involves those processes that characterize specifically the maintenance activity, such as management of work orders, planned maintenance activities, spare parts management, etc;
- *control*: component responsible for the control of costs and economic/technical performance;
- *improvement*: subsystem through which the performance improvement becomes a systematic activity.

A Computerized Maintenance Management System (CMMS) represents the computerization of the Maintenance Management System and differs slightly, moving towards a simplified and modular structure to provide greater flexibility and adaptability to different companies.

The software market offers many solutions for CMMS, characterized by structure with different modules. However, the various modules can be collected in four main areas:

- *Plant data*: section of the CMMS which collects all the information related to the environment, such as the assets and plant archives, the components archives and any other relevant information related to the system.
- *Spare parts*: area devoted to the inventory management (components and spare parts), and also to the management of equipment and measurement tools. One of its key functions is recording the inputs-outputs of the warehouse.
- *Work orders*: section of the CMMS responsible for the management of all the maintenance interventions. Its basic document is the work order. This module should be responsible not only for recording all work orders (planned or emergency), but also for planning all the interventions, monitoring the progress of the activities and even for personnel management.
- *Purchase orders*: section that deals with the management of purchase orders and in general of all the external supplies (both material and labor).

The Computerized Maintenance Management Systems (CMMS) enable the facility manager, subordinates and customers to track the status of the maintenance work on their assets and the associated costs of that work. CMMS are used to record, manage and communicate all the day-to-day maintenance operations. The system can provide reports to use for the organization resources management, for preparing facilities key performance indicators (KPIs)/metrics to use in evaluating the effectiveness of the current operations and for making organizational and personnel decisions. In today's maintenance world the CMMS is an essential tool for the modern facilities maintenance organization.

3. *Design of the survey*

Basing on the reference model above presented, a descriptive survey has been designed.
A survey is a technique used to gather information about a population. A survey usually takes the form of a questionnaire to be filled by a significative sample of a population [28].
The reference papers used to design the survey have been those of Forza Cirpiano [12], Arleck and Settle [29], Fink and Kosecoff [28] and Marczyk, De Matteo, Festinger [30].
In the design of a survey, some basic steps should be followed, as suggested by Alreck and Settle:

- definition of the aims of the survey;
- definition of the sample;
- design of the questionnaire;
- data collection;
- data analysis and interpretation;
- results reporting.

These steps are not independent, but interrelated (as showed in the picture below).

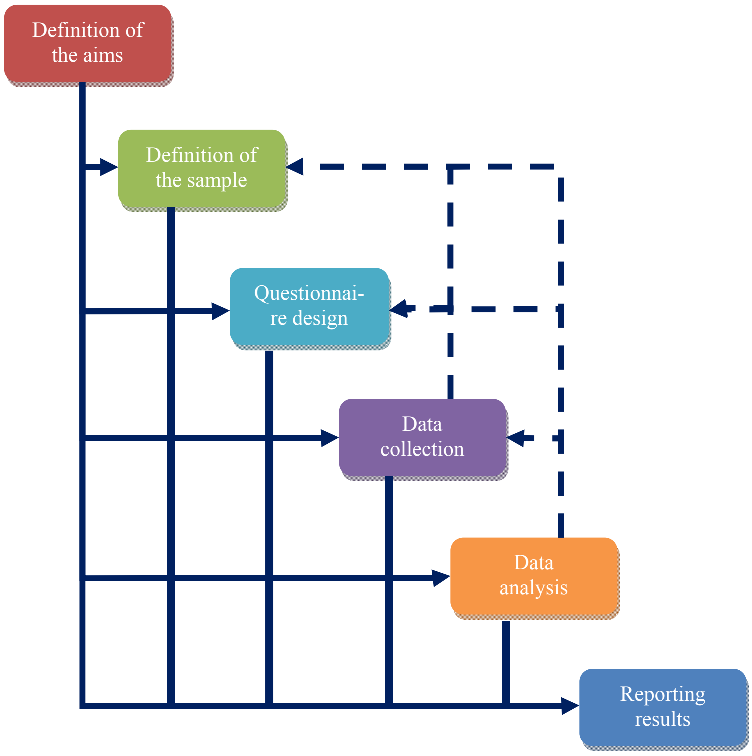


Figure 4: Survey design steps

3.1 *Aims of the survey*

As explained in chapter 3, the aim of this survey is to:

1) assess the current level of knowledge, implementation and automation in companies of:
   - integrated methodologies, approaches and tools for maintenance;
   - special purpose software;
   - information flows;
2) assess if companies, that have implemented such integrated solutions for maintenance, use it along the lifecycle of their production plant;

3) investigate the correlation among several company's structural variables and the maturity level of adoption for integrated methodologies, approaches and tools for maintenance along the plant lifecycle;
4) identify the success elements and the barriers that promote or inhibit this integration;
5) assess the potential interest of companies for a future implementation of integrated solutions.

3.2 *Definition of the sample*

As clearly highlighted in the previous chapters, the focus of this work is the plant. To ensure this perspective and simultaneously characterize the diversity of players on maintenance market, it has been decided to submit this survey to two types of company:

- companies that perform maintenance on their own plants,
- companies that perform maintenance on plants of third parties.

Therefore, the survey is composed by two separate questionnaires, one for each type of company interviewed.

Concerning companies that perform maintenance on their own plants, only process and manufacturing companies have been taken into account. In a first moment, it was decided to involve in the survey as many companies as possible, without considering the different market sectors, but after the first 7 interviews emerged that the market sector was one of the biggest inhibitor/catalyst for the implementation of integrated solutions in maintenance. Considering the industrial context available in term of closeness and suitability, it was decided to involve only companies that produce and manufacture paper and companies of the chemical/pharmaceutical sector.

Concerning companies that perform maintenance on plants of third parties, has not been achieved a statistically significant sample, therefore the analysis of this category is put off to a future research.

The text of two questionnaires of the survey are reported in the Attachment A.

3.3 *Design of the questionnaire for companies that perform maintenance on their own plants*

This questionnaire is divided into five different sections (see the questionnaire attached to this paper):

1. introduction;
2. general information (questions from n°1 to n°10);
3. characteristics of production technology (questions from n°11 to n°18);
4. maintenance strategy (questions from n°19 to n°25);
5. implementation of maintenance tools and methodology, their integration and related information flow adoption (questions from n°26 to n°31).

Each section defines and measures variables; the data collection from a statistically significant sample and the subsequent data analysis has allowed the author to identify all the possible links between these variables.

The scales used for the answers in the questionnaire are of different types and are shown below in the description; an important issue on questionnaire is the use of particular symbols:

○ in case of multiple choice answers where is possible to select only one choice;
□ in case of multiple choice answers where is possible to select more than one choice.

3.3.1 Introduction

A brief introduction explains the aim of the survey and which are the benefits for companies involved: companies interviewed will receive indications about their degree of maturity on the issues proposed and their positioning on the global context. This survey will represent a benchmarking, an useful process of comparing the integrated maintenance approach adopted by the company interviewed to the practices adopted by the "best in class", especially if competitors.

3.3.2 General information

This section contains questions useful to classify the Company interviewed:

- revenue (question n°3);
- workforce (question n°4);
- group affiliation (question n°6);
- type of industry (question n°7);
- business strategy adopted (question n°10);
- information about plants operated: type, phases of the plant lifecycle that involve directly the company (design, construction, operation, dismantling) (question n°8);
- information about plant subjected to special regulations (question n°9).

The classification of the type of industry (question n° 7) has been performed in accordance with the NACE/DB03 classification (Nomenclature générale des Activités économique dans les Communautés Européennes), mandatory for EU members from January 1°, 1993.
The choice of the model used to define the business strategy (question n°10) adopted by companies interviewed deserves some considerations. The debate about the business strategies, started in the sixties, in particular with the work of Chandler [42], has not yet led to a consolidated and shared definition of strategy. Because this is not relevant to the purposes of this study, this work will restrict itself only to some considerations and some definitions.
One of the main aim of a business strategy is to achieve a competitive advantage, beating the competitors in those markets where the company has chosen to operate. To succeed, it is fundamental that all business functions cooperate coherently with the business strategy adopted. This additional layer of strategy is called functional or operational.
According to Hax and Majaluf [39], strategy is intended as a coherent and unifying pattern of decisions; it determines and reveals the purposes of the company; chooses the markets in which the organization wants or will compete; pursues a long-term competitive advantage in each business in which has decided to compete, involving all the company hierarchical levels (corporate, business, functions); defines the nature of the economic and non-economic contributions it intends to make to the organization as a whole.
To classify the business strategy of the companies interviewed, has been chosen the model of Porter [31], because it is simple and able to provide a sufficient level of detail. This model identifies the business strategy adopted using the following classification:

- cost leadership strategy,
- differentiation strategy (in terms of innovation, service level, quality, performance),
- market segmentation strategy.

3.3.3 Characteristics of production technology

As asserted by Pinjala, Pintelon and Vereecke [32], in order to investigate on a possible relationship between business and maintenance strategies, it is inevitable to firstly pass through the manufacturing strategy. To characterize the production context, Pinjala, Pintelon and Vereecke use the matrix of Hayes and Wheelwright [38].

Although this matrix is subject of many Operations Management courses, its importance has changed over the years as deemed too simple to be able to describe the complexity of modern production environments.
Many modified versions of the Hayes and Wheelwright matrix have been proposed (Krajeswski and Ritzman [34], Gaither and Fraizer [35]) and numerous studies have attempted to validate or reject the matrix. Kemppainen, Vepsalainen, Tinnila [36] present an interesting list of the studies carried out to test the validity of the matrix. One of the most discussed points in the scientific literature concerns the comprehension of the impact of integrated production systems on the positioning of companies in the product-process matrix. Researchers agree that, in the matrix, the area of positioning is not strictly based only on the diagonal of the matrix, but also around it. Ariss and Zhang [37] argue that this area around the diagonal, where companies are positioned, is bigger on the upper left corner of the matrix than on other parts.
During the design of the questionnaire, it seemed too limited considering the matrix of Hayes and Wheelwright as the only element able to describe the complexity of the existing production environments. Assuming that is essential, for the comprehension of the choices that characterize the maintenance strategy, to understand in which context the company competes and which is its organization and its manufacturing approach, a deeper analysis of these issues has been preferred, using in part the work of Laura Swanson [33].
As a consequence of this, in accordance with Laura Swanson, a modified version of the matrix of Hayes and Wheelwright [38] has been used to characterize the manufacturing strategy (question n°11 – see the questionnaire attached). This matrix, shown on table 2, divides production technology into four generic categories associated with different level of technical complexity: job shop technology, small batch technology, large batch-line technology and continuous process technology. For each category it is asked to specify the degree of adoption (in this way it's possible to consider the frequent situation of companies that adopt different production technologies).

Table 2: manufacturing strategy adopted (question n°11)

	Degree of adoption					
	Do not have	Used minimally		Use moderately		Used extensively
	0	1	2	3	4	5
Job shop technology: production of single or small quantities of a large number of different products, according to direct specifications of the customer.						
Small batch technology: production of small batches with large variety.						
Large batch – Line technology: production of large batches and low variety.						
Continuous process technology: production of huge volumes of a single product or a very limited range of products.						

As asserted by Swanson [33], in order to assess how production technology influences maintenance management, three characteristics have been considered:

- technical variety;
- interdependence;
- technical complexity.

To characterize the technical variety the authors adopted the parameters used by Swanson, asking to specify by a Likert scale if (see table 3):

- a single type of production equipment represent more than 80% of total plant production equipments, or no single type of equipment represents more than 20%;
- the production equipments are supplied by few or many different OEM'S (Original Equipment Manufacturers);
- the production equipments are standard or customized equipments.

Table 3: technical variety (question n°12)

A single type of production equipment represents more than 80% of total plant production equipments	1	2	3	4	5	No single type of production equipment represents more than 20%
The production equipments are supplied by few OEM'S	1	2	3	4	5	The production equipments are supplied by many different OEM'S
The production equipments are standard	1	2	3	4	5	The production equipments are customized

It is also asked to quantify the frequency (from very low to very high) of different types of failures (recurrent, intermittent, unusual) that occur on equipments (see also table 4).

Table 4: technical variety (question n°13)

Recurrent failure	✓ Very low ✓ Low ✓ Medium	✓ High ✓ Very high
Intermittent failure	✓ Very low ✓ Low ✓ Medium	✓ High ✓ Very high
Unusual failure	✓ Very low ✓ Low ✓ Medium	✓ High ✓ Very high

Intermittent failures are failures that do not manifest themselves all the time. They are permanent alteration of a component that leads to periods of active fault alternating with periods of latent failure. The fact that they are sometimes detectable and sometimes not, can make them very difficult to analyze.

Where the technical variety is low, is expected that the prevalent failures are recurrent, while where the technical variety is high, is expected that the frequency of unusual failures is higher than the previous case. This will be verified in the chapter related to the data analysis. It is evident that the failure rate is an important element for the definition of the maintenance strategy.

To characterize the technical complexity two parameters have been adopted: one is identified by the question n°15 where it is asked to indicate the percentage of machines that implement flexible integrated automation (Flexible Manufacturing Systems, Flexible Assembly Systems, Flexible Manufacturing Line, Flexible Manufacturing Cell, Automatic Transfer Line, Numeric Control); the other is identified asking how many time (from very low to

very high) is needed to identify the failure, to prepare the intervention, to repair the failure and to restart the plant (question n°14). Concerning the definition of the indicators most appropriate to provide an explanatory description of the plant technical complexity and, at the same time, most comprehensible for the interviewed, some considerations are necessary.
Swanson [33] highlights her awareness about the limitations of the product-process matrix, in particular for the increasing adoption of integrated production systems, and about the limitation that only one generic production technology category is not sufficient to fully characterize a plant. Therefore, to define the technical complexity Swanson proposes a modified version of the matrix of Hayes and Wheelwright.
In this work, this solution has been considered important but not sufficient. However, the use of entropic measures to quantify the complexity of systems, such as in the work of Calinescu, Efstathiou, Sivadasan, Schirn and Huaccho Huatuco [43], seemed a way too complex to pursue.
Because of a substantial lack, in the scientific literature, of measures of the technical complexity, it was decided to introduce two corrective factors to the matrix proposed by Swanson (that has been used to define the manufacturing strategy): the presence of machines that implement flexible integrated automation express in percentage (as also proposed by Ilyukhin, Haley and Singh [44]) and the incidence of all the phases of the process for the failure elimination (without a distinction between failure of electrical, mechanical, electronic, hydraulic or pneumatic nature, because is not necessary a level of detail so high). Therefore, as the technical complexity increases, is reasonable to presume a growing importance of the time of failure diagnosis.

The interdependence is the degree of collaboration required among units to produce a finished product or service. The interdependence is a function of the production planning techniques and of the production technologies. It has therefore been described by the parameters listed in Table 5 (question n°16) and by the percentage of the production process phases that stop within the first hour of a singular machine breakdown (question n°17). It is also asked to give an age-group classification (in percentage) of equipments installed (question n°18).

Table 5: interdependence (question n°16)

No buffer stocks between the phases of the production process	1	2	3	4	5	Buffer stocks between all the phases of the production process
If a breakdown occurs, no re-routing of work is possible	1	2	3	4	5	If a breakdown occurs, work is easily rerouted through the plant
Rigid production flow	1	2	3	4	5	No rigid production flow

The information collected in the "General Information" and "Characteristics of production technology" sections seemed sufficient to characterize the context where the maintenance function operates. This was confirmed by the work of Riis, Luxhoj, Thorsteinsson [45] that pays particular attention to the importance of the production context and adopts the same factors used in this work. Unlike them, however, it was not considered the possible influence of the degree of horizontal and vertical integration of the company.

3.3.4 Maintenance strategy

Also for what concerns the maintenance strategy, there isn't in the scientific literature a substantial agreement on its definition. Fedele, Furlanetto and Saccardi [46] distinguish between maintenance policy and maintenance strategy: the latter occurs in a second time, characterizes the operational approach to the maintenance problems and should be developed according to the criteria provided by the maintenance policy adopted. The maintenance policy, instead, provides guidance on the approach that the company takes with regard to the maintenance problems. The TPM (Total Productive Maintenance) and the RCM (Reliability Centered Maintenance) are considered by Fedele, Furlanetto and Saccardi maintenance policies. A substantial agreement with this line of thought is also present in Kevin and Pensky [49] and Cooke [47].

However, trying to operate in a systematic way as possible, this work accords with the definition of Pinjala, Pintelon and Vereecke [32]. They, in analogy to the definition of strategy provided by Hax and Majluf [39], define maintenance strategy as "*a coherent, unifying and integrative pattern of decisions in different maintenance strategy elements in congruence with manufacturing, corporate and business level strategies; determines and reveals the organizational purpose; defines the nature of economic and non-economic contributions it intends to make to the organization as a whole*".

In order to investigate, in this work, on a possible relationship between the degree of implementation of integrated methodologies and tools in industry and the maintenance strategy adopted, it is inevitable to firstly pass through the manufacturing strategy and then through the maintenance strategy. Therefore, the variables of the maintenance strategy have been defined in analogy with those of the manufacturing strategy.

One of the most widely used models for the definition of the manufacturing strategy variables is the model of Hayes, Wheelwright and Clark [48] (extension of the model of Skinner [50]), showed on Table 6. In analogy with this structure, Pinjala, Pintelon and Vereecke [32] developed a model (Table 7) where are defined the variables that characterize the maintenance strategy.

Table 6: manufacturing strategy variables - model of Hayes, Wheelwright and Clark [48]

STRUCTURAL VARIABLES

Capacity	Production capacity, shift patterns, temporary subcontracting policies.
Facilities	Size, location and specialization of resources.
Technology	Production equipment, automation and configuration of equipment.
Vertical integration	In-house production versus outsourcing, and relationship with suppliers.

INFRASTRUCTURE VARIABLES

Organization	Structure and design.
Quality policy	Quality assurance, control practices and policies.
Production control	Production planning and inventory control systems.
Human resources	Policies and practices, including management selection and training policies.
New product development	Process and organizational aspects.
Performance measurement and reward	Performance recognition and reward systems.

Table 7: maintenance strategy variables – model of Pinjala, Pintelon and Vereecke [32]

STRUCTURAL VARIABLES

Maintenance capacity	Capacity in terms of work force, supervisory and management staff. Shift patterns of work force, temporary hiring of work force.
Maintenance facilities	Tools, equipment, spares, workforce specialization (mechanics, electricians, etc.), location of workforce..
Maintenance technology	Predictive maintenance, or condition monitoring technology, expert systems, e/I maintenance technology (intelligent maintenance).
Vertical integration	In-house maintenance versus outsourcing and relationship with suppliers.

INFRASTRUCTURE VARIABLES

Maintenance organization	Organization structure (centralized, de-centralized, or mixed), responsibilities.
Maintenance policy and concepts	Policies like corrective, preventive and predictive maintenance. Concepts like Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM).
Maintenance planning and control systems	Maintenance activity planning, scheduling. Control of spares, costs etc. Computerized Maintenance Management Systems (CMMS).
Human resources	Recruitment policies, training and development of workforce and staff. Culture and management style.
Maintenance modifications	Maintenance modifications, equipment design improvements, new equipment installations and new machine design support.
Maintenance performance measurement and reward system	Performance recognition, reporting and reward systems.

The structural variables are those elements that cannot be modified in the short term and absorb the largest portion of the maintenance budget. The transition from a outsourced maintenance to an in-house maintenance, for instance, requires big capital investment, time to find resources, qualified workforce, etc.

The infrastructure variables are generally linked to aspects of the company more operational, such as the production processes, the size or the degree of automation.

In this work the model of Pinjala, Pintelon e Vereecke has been adopt to define the maintenance strategy variables. This choice is due to the decision to proceed in a systematic and unifying way, without loss of generality and loss of information completeness. Moreover, similar definitions of the maintenance strategy variables can be found in many other works, as Upshall [51], Jonsson [52], Marshall Institute [53], Benchmark Research & MCP Management [54] e Tsang [55].

Not all the variables of the model of Pinjala, Pintelon e Vereecke have been adopted during the design of the questionnaire. Below are examined in detail the variables assumed.

Vertical integration of maintenance

Rigid organizations, where all the maintenance activities were performed completely in-house, evolved in the 70s toward more flexible structures, as required by the market, outsourcing some activities. Today, the spur for outsourcing of the non core business activities is still very strong; the modern companies require a robust optimization to face the market variability and cyclicity. Besides, companies are interested to maintain and increase their

internal knowhow and put great emphasis on all issues that contribute to the generation of the product cost [56].
Even if is present a common denominator that drives companies to pursue the path of outsourcing, there are specificities different from case to case: in some situations the predominant aspect is the profit, in others is the search of specialized competences, difficult to find in-house.
Before investigating the organization of the maintenance performed in-house, it is important to understand which activities are carried out internally and which are outsourced. Therefore a question (question n°19) asks if maintenance is performed in-house, if it is partially outsourced (with maintenance engineering and management in-house) or totally outsourced (global service contracts).

Maintenance Organization
Maintenance often has operated and operates not as an independent business function, but as a sub-function of the production. In the 60s, as a result of the increasing mechanization, computerization and automation, maintenance started to be identified as an independent business function with its annual budget. Between business functions there are links and interdependencies, particularly delicate are those between Maintenance, Production and Engineering.
The relationship between Engineering and Maintenance will be examined in more detail in the maintenance policies chapter.
Maintenance function and Production function have in common the production plant at which divergent interests converge in the short term: Production aims at the maximum utilization of the plant, while Maintenance needs stops of the plant for inspections and repairs. For these reasons it is important to clearly define the dependency and mutual position of the two functions, the level of decentralization of maintenance in the production areas and the level of knowledge about maintenance issues by the production personnel [56].
For what concerns the positioning of maintenance within the organization chart, scientific literature shows a lack of papers sufficiently exhaustive and systematic. An important contribution comes from Niebel [57]: he asserts that the hierarchical positioning of maintenance varies with the size, complexity and the products of the company. Generally the maintenance manager reports to the production manager, except in the case of small companies where the two figures coincide. The Engineering function, in addition to the maintenance engineering, should also include other disciplines such as the reliability engineering, the activities scheduling, the standards development and the inspection activity that should support the maintenance management. The chief engineer reports to the production manager.
Adopting this structure as a base, the questionnaire asks (question n°20) if maintenance is a business function of the company. If so, it is asked to specify the annual budget. If not, it is asked within business function it is contained.
Concerning the level of decentralization of maintenance within the production departments, both Niebel [57] and Marquez and Gupta [22] agree that there are three possibilities: centralized maintenance, decentralize maintenance and mixed maintenance (and this information is asked by question n°21).
In a context of centralized maintenance, the reference figure is the maintenance manager. All the activities, equipment and spare parts are managed centrally in order to exercise a strong control of the maintenance policies, of the procedures, of the training and achieve an efficient allocation of the resources. The main disadvantages of the centralized maintenance lie in its rigidity that led to implement solutions more decentralized able to provide improvements at the level of communication and coordination in complex technical environ-

ments [33]. However, it's important to note that increasing the degree of decentralization increases the probability to lose sight of the productive context in which maintenance operates, leading to the generation of inconsistencies between manufacturing strategy and maintenance strategy.
In order to understand, at an organizational level, the relevance of the Maintenance Engineering, has been included a question (question n°22) that asks if there is distinction between Maintenance Management and Maintenance Engineering. It is opportune to highlight the use of the term "distinction", in accordance with the terminology used in the Introduction. In that case, speaking of the increased importance of the Maintenance Engineering, it was associated with the term "role" and not with the term "function", because the purpose was to emphasize the importance of its presence primarily as an organizational solution rather than as another business function.

Maintenance Capacity
According to Laura Swanson [33], it is asked to specify the number of graduated engineers, supervisors and technicians that operate in the maintenance engineering and in the maintenance management functions (question n°22). With this question, the variable "Maintenance capacity" is completely defined.

Maintenance Policies
The maintenance policies considered in this work have been the corrective maintenance, the preventive maintenance and the predictive maintenance.
For a correct interpretation of data coming from interviews, it is necessary to define, before, strengths and faults of each maintenance policy, trying to understand which are the factors that drive the adoption of one specific policy.

Corrective Maintenance
Corrective maintenance is the most ancient, simple and spontaneous fault response. This policy should be adopted in case of unexpected or catastrophic failure, condition that a good maintenance activity should prevent a priori. The idea that drives its adoption is that in presence of non-critical low cost systems, easy to replace, is better to wait that the failure occurs, before taking action. It may happen, in fact, that the reduction of downtimes and the increase of availability are not sufficient to pay the additional costs arising from more sophisticated maintenance policies.
The main disadvantages of this policy are:

- failures occur randomly and often at inconvenient times;
- a fault of a component can have serious consequences on other elements of the system;
- unscheduled interventions require often a long time (to obtain spare parts, find the appropriate technicians, etc), slowing down the production and keeping busy the technical staff in not profitable actions.

Preventive Maintenance
Preventive maintenance is a schedule of planned maintenance actions that aim at the prevention of breakdowns and failures. The primary goal of the preventive maintenance is to prevent the failure of equipment before it actually occurs. It is designed to preserve and improve the plant reliability by replacing worn components before they actually fail. Preventive maintenance includes equipment checks, partial or complete overhauls at specified periods, oil changes, lubrication and so on.

This policy, which has been successful especially over the years' 60 and 70 (because it answered the need to provide a scientific base and a scheduling of the maintenance operators actions), often is considered unduly expensive if indiscriminately adopted, with no significant effect on the plant availability. This is true for some components; however, it should be considered not only the costs but also the long-term benefits and savings associated with the breakdowns not occurrence. Preventive maintenance is a logical choice if, and only if, the following two conditions are met:

- The component in question has an increasing failure rate. In other words, the failure rate of the component increases with time.
- The overall cost of the preventive maintenance action must be less than the overall cost of a corrective action. (Note: In the overall cost for a corrective action, one should include ancillary tangible and/or intangible costs, such as downtime costs, loss of production costs, lawsuits over the failure of a safety-critical item, loss of goodwill, etc.)

If both of these conditions are met, then preventive maintenance makes sense.

Predictive Maintenance

A more modern vision of the maintenance problems has led to the use of non-destructive techniques to check systems, in order to identify, with considerable advance, the presence of faults and schedule the most suitable intervention. This approach, called predictive maintenance, determine the condition of in-service equipment in order to predict when maintenance should be performed (and therefore schedule the maintenance interventions). This policy allows to avoid unexpected downtimes or catastrophic chain reactions, improving the overall reliability.
This maintenance policy not only assure economic and operational advantages, but also has important implications for the design phase: in fact, to minimize the downtimes due to the inspections, it is necessary that the system is equipped with a set of devices and sensors for the detection of the asset conditions.

To proper characterize the maintenance policy variable, in the questionnaire is asked (question n°21 bis) to specify, in relation to the total number of maintenance interventions on the equipments, the percentage of actions of corrective, preventive and predictive maintenance (as showed in table 8).
In the questionnaire it is also asked to highlight if DFR/DFA (design for reliability/availability) techniques are adopted (question 22 bis).

Table 8: maintenance policy variable (question n°21 bis)

Corrective Maintenance	✓ Low (<30 %) ✓ Medium (30-45 %) ✓ High (>45 %)
Preventive Maintenance	✓ Low (<30 %) ✓ Medium (30-45 %) ✓ High (>45 %)
Predictive Maintenance	✓ Not performed ✓ Low (<20 %) ✓ High (>20 %)

Maintenance Planning and Control Systems

Concerning the Computerized Maintenance Management System (treated before), the questionnaire asks if a CMMS is adopted and if it is integrated in the ERP or it is a stand-alone software (question n°23). If adopted, it is asked to specify the name of the software used and which modules have been implemented. If not, direct questions are proposed about the barriers to its implementation; (see table 9).

Table 9: maintenance planning and control system variable - CMMS adopted (question n°23)

o **INTEGRATED (ERP module)**	
YES	✓ Software: o SAP o NAVISION o ORACLE o Customized software. Name:_______________ o Other. Name:_______________ ✓ Modules contained into the ERP ☐ Finance ☐ Controlling ☐ Treasuring ☐ Project System ☐ Production Planning ☐ Plant Maintenance ☐ Sales & Distribution ☐ Human Resources ☐ Material Management ☐ Quality Management
NO	o Our company is not ready for its implementation o Too expensive, but we consider it strategic for our company o Not strategic for our company o Our company has a stand-alone software
o **STAND-ALONE**	
YES	✓ Software: o MAXIMO o DATASTREAM o Customized software. Name:_______________ o Other. Name:_______________
NO	o Our company is not ready for its implementation o Too expensive, but we consider it strategic for our company o Not strategic for our company o Our company has a stand-alone software

The questionnaire asks also to specify in which activities the CMMS is employed and how frequently it is used (question n°24, as shown in table 10).

Table 10: maintenance planning and control system variable - CMMS activities (question n°24)

☐ Planning and scheduling of work orders	o Never o Rarely o Frequently o Systematically
☐ Planning of maintenance activities (preventive and predictive)	o Never o Rarely o Frequently o Systematically
☐ Data recording of works performed	o Never o Rarely o Frequently o Systematically
☐ Spare parts management (inventory)	o Never o Rarely o Frequently o Systematically
☐ Spare parts management (purchasing)	o Never o Rarely o Frequently o Systematically
☐ Maintenance workforce management	o Never o Rarely o Frequently o Systematically
☐ Maintenance costs budgeting and reporting	o Never o Rarely o Frequently o Systematically
☐ Data reporting of maintenance works performed	o Never o Rarely o Frequently o Systematically
☐ Data base for availability/reliability analysis	o Never o Rarely o Frequently o Systematically
☐ Data base for the optimization of the maintenance policies	o Never o Rarely o Frequently o Systematically
☐ Data base for the redesign of components or equipment	o Never o Rarely o Frequently o Systematically

Human Resources
An important aspect for the comprehension of the degree of exploitation of the maintenance workforce is the average time spent per year for training on issues of maintenance (question n°24 bis). It has been made a distinction between graduated engineers, supervisors, maintenance technicians and production operators, in order to obtain a greater level of detail and also to understand if companies involve production operators in maintenance (in line with the TPM philosophy). This concept is further underlined by another question, that asks the degree of involvement (low, medium, high) of production operators in routine maintenance interventions, resettlement of simple breakdowns, works of preventive maintenance and works of predictive maintenance (question n°25).

3.3.5 Implementation of maintenance tools and methodology, their integration and related information flow adoption

This section of the questionnaire is the one that refers in more detail to the reference model and to the information flows mapped onto it. In order to facilitate the subsequent data analysis, four tables have been designed:

- one concerning the level of implementation of the various areas of the reference model (see question n°26);
- one related to the software used in the different areas (see question n°29);
- one related to the software planned for a future implementation (see question n°30);
- one concerning the level of implementation of the information flows between the areas of the model (see question n°31).

The first table asks questions about the current level of implementation of each area of the reference model (an example is showed on Table 11, with regard to the area MEO). It's obvious, in fact, that there's no sense in investigating on the presence of special purpose software or informative flows if the relative areas are not implemented.
If the above areas are implemented, it is asked to specify the importance perceived using a Likert scale. This information together with the knowledge of the level of implementation is enough to assess the present situation into the company, concerning these issues. It could be of a great interest, for instance, investigate those situations where an area is implemented, but its importance perceived is very low.
If not implemented, it is asked to specify if a future implementation is planned. We ask as well to quantify on a Likert scale their potential importance. The assessment of the difference between importance perceived and potential importance is an useful indicator of the degree of interest in this implementation and it is different from the measure of urgency, quantified by the questions on future implementation. Besides, it could be present a significant potential importance for those areas where the implementation of the an information flow is planned.

Table 11: implementation of the areas of the reference model (question n°26)

RME PROCESS AREAS				
RME Process Areas	Current level of implementation	Importance perceived	Future implementation (if not implemented at the moment)	Potential importance
MEO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5

If the Maintenance Engineering area is implemented (MED and/or MEO), question n°27 asks to specify which methodologies are adopted (FTA, ETA, FMECA, RBD, HAZOP, ILS).
After the definition of the areas implemented or planned for a future implementation in the company interviewed, the second table investigates, for each area, (see Table 12) the presence of special purpose software. The description of the present situation for what concerns the use of software is completed asking to specify the importance perceived.

Table 12: present special purpose software (question n°29)

RME SOFTWARE TOOLS TABLE - PRESENT			
RME Process Areas	Software implemented and utilization rate		Importance perceived
MEO	o Not present o Limited utilization o Significant utilization o Systematic utilization	Name: ✓ ________ ✓ ________ ✓ ________	o 1 o 2 o 3 o 4 o 5

Concerning the future implementations, the third table asks if an introduction of special purpose software is planned in the short, medium or long period (see Table 13). In analogy with the table 11 it is also asked to quantify the potential importance of these tools.
The information and conclusions that can be drawn from these data are comparable to those reported during the examination of questions about the areas of the reference model.

Table 13: future special purpose software (question n°30)

RME Software Tools Table - Future			
RME Process Areas	Planned implementation		Potential importance
MEO	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	Name: ✓ ________ ✓ ________ ✓ ________	o 1 o 2 o 3 o 4 o 5

The last, but not least, part of the reference model to be examined, is that relative to the information flows exchanged between the areas. Before proceeding to a description of the fourth table and its questions, it should be highlighted the difficulty arose in finding an instrument simple and not subjective, able to measure the value attributed to an information flow.
For each information flow has been carried out a table (as the Table 14 for the MMO-MEO flow). In analogy with the previous tables, there are questions about the current level of implementation, the planned future implementations, the importance perceived and to the potential importance.
If an information flow is implemented, it is asked to specify the typology of communication (if manual or automated), the flow rate and if more automation is required.

Table 14: information flow (question n°31)

<table>
<tr><td>Operation Stage</td><td colspan="6">Current Level of Implementation</td></tr>
<tr><td rowspan="7">**MMO-MEO**</td><td colspan="2">Level of implementation</td><td colspan="2">Typology of communication</td><td colspan="2">Flow rate of information exchange</td></tr>
<tr><td colspan="2">o Not present
o Limited
o Significant
o Complete</td><td colspan="2">o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td colspan="2">How many loops?</td></tr>
<tr><td colspan="6">Future implementation</td></tr>
<tr><td colspan="6">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td colspan="2">Importance perceived</td><td colspan="2">Potential importance</td><td colspan="2">Interest in an automated information exchange</td></tr>
<tr><td colspan="2">o 1
o 2
o 3
o 4
o 5</td><td colspan="2">o 1
o 2
o 3
o 4
o 5</td><td colspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

3.4 *Design of the questionnaire for companies that perform maintenance on third parties' plants*

The questionnaire for companies that perform maintenance on third parties' plants has the same purpose, but presents some differences.

3.4.1 *General information*

This section has been carried out in analogy with the same section of the questionnaire for companies that perform maintenance on their own plants. The main difference lies in the characterization of the company interviewed not specifying what type of industry it is, but specifying the typology of services provided.

To classify these services has been adopted the classification proposed by Furlanetto and Mastriforti [40]:

- Engineering;
- Engineering, Procurement and Construction (EPC contract): the contractor designs the plant, procures all the necessary materials and constructs it;
- Operational services with clearly-defined responsibilities: services that involve responsibility of the service provider limited to the effectiveness of individual commitments. These activities generally are scheduled and end with the testing of works performed by service provider. Usually the contract for this kind of services excludes a "thinking" involvement of the service provider. Examples are the operations of corrective maintenance;

- Maintenance Engineering and Management Services: include commitments generally placed in the maintenance engineering and management. Examples are the realization of inspection plans, price lists, maintenance plans and so on;
- Global Service contracts for maintenance: contract for turnkey maintenance services with full responsibility of the service provider;
- Global Service at Life Cycle Costs contracts for maintenance: this contract involves the purchase of "productive functionality" of a technological system along a wide span of time. Examples of "productive functionality" are the plant availability, the production volume and so on.
- Consulting.

For each service it is asked to specify if and how (as percentage of the total services provided) it is performed.

3.4.2 Company Organization

The section referring to the characteristics of production technology of the other questionnaire has been replaced by one referring to the company organization with questions on the legal form (if independent business unit with its profit and loss account or autonomous company, according with the classification of Perona et al. [41]), the internal articulation (by geographical area, type of client, type of service provided and industrial sector served) and the displacement of staff to customers.

3.4.3 Maintenance strategy and Implementation of maintenance tools and methodology, their integration and related information flow adoption

All the questions contained in these two sections are the same of the questionnaire for companies that perform maintenance on their own plants, except for those related to the degree of vertical integration and the maintenance organization, because not relevant.

4. *Testing of the questionnaires*

After the design of the two questionnaires, some problems emerged:

- the questionnaire had to be tested in order to verify if all the questions were correctly understood and responded to the needs of the investigation (a sort of pre-test of reliability and validity);
- the questionnaires were designed to be submitted through an interview (the so-called assisted type submission). Therefore emerged the need to train the interviewers;
- the questionnaires were conceived to be submitted to two different kinds of companies: companies that perform maintenance on their own plants (specifying if process or manufacturing industries) and companies that perform maintenance on third parties' plants. Interviewing different companies during the testing phase it has been possible to identify the typology of companies more helpful and sensible to the issues treated.

The questionnaires were, therefore, submitted to 7 different companies:

- ✓ Lilly Italia
- ✓ SunChemical
- ✓ I.V.V. Industria Vetraria Valdarnese
- ✓ Polynt spa
- ✓ Manetti & Roberts
- ✓ Whirpool
- ✓ Elyo

Only one of these firms was a company that performed maintenance on third parties' plants (Elyo). This highlighted the complexity to find company of this typology to involve in this work. The main difficulty consisted in a lack in the center Italy of company of this type, with a structure big enough to be of interest for this work.

About the other 6 companies, 4 were companies of the chemical/pharmacological area. This sector, together with the paper sector, have been the two areas studied (this will be discussed in more detail in the section concerning the sample design).

Before discussing the modifications introduced after this testing phase, it is necessary to introduce two concepts: the reliability and validity of the survey results.

The utility and credibility of survey results are, in fact, strongly linked to their reliability and validity.

Reliability means that the results are not affected by random error. According to Kerlinger [58] and Carmines and Zeller [59], Reliability indicates dependability, stability, predictability, consistency and accuracy, and refers to the extent to which a measuring procedure yields the same results on repeated trials.

Reliability must be evaluated after data collection. The four most common methods used to assess reliability are:

- test-retest method;
- alternative form method;
- split halves method;
- internal consistency method.

If random errors increase, the reliability of the sample decreases. The sources of random errors can be many: language difficult to understand or errors in the sampling of the population and so on.

Validity means that the survey is able to provide the information necessary to answer the questions of its design goal. A "valid" survey is a survey not affected by external factors that push or pull the results in one direction rather than another, introducing a systematic error (bias).
Validity can be broken down into two categories: internal validity and external validity.
External validity refers to the extent to which the results obtained are generalizable or transferable. Results with a low level of external validity cannot be generalized, therefore the sample considered is not representative of the whole population.
Internal validity refers to:

- the rigor with which the study has been conducted (e.g., the study's design, the care taken to conduct measurements, and decisions concerning what was and wasn't measured)
- the extent to which the designers of a study have taken into account alternative explanations for any causal relationships they explore.

There are several types of internal validity:

- Face Validity: Face validity is concerned with how a measure or procedure appears. Does it seem like a reasonable way to gain the information the researchers are attempting to obtain? Does it seem well designed? Does it seem as though it will work reliably? Face validity does not depend on established theories for support
- Criterion Related Validity : is proved by comparing the results obtained with a value that is accepted as a standard indicator of that variable (the so called "gold standard") or, more often, with the results of other surveys that are already widely used and validated.
- Construct Validity: is related to the degree to which a procedure is able to measure the theoretical construct that should be measured. Construct validity seeks agreement between a theoretical concept and a specific measuring procedure. For example, a researcher inventing a new IQ test might spend a great deal of time attempting to "define" intelligence in order to reach an acceptable level of construct validity.
  To understand whether a piece of research has construct validity, three steps should be followed. First, the theoretical relationships must be specified. Second, the empirical relationships between the measures of the concepts must be examined. Third, the empirical evidence must be interpreted in terms of how it clarifies the construct validity of the particular measure being tested.
- Content Validity: Content Validity is the degree to which a measure is the complete representation of the concept of interest. It examines if all the main aspects of the object to analyze have been included in the valuation (possibly in the correct proportions). In general, the presence of this type of validity is certified by experts.

In this work the internal validity has been pursued, trying to adopt variables and measures proposed by other validated works found in the scientific literature. As described in the chapter 3 (Design of the survey), the questionnaires are the "extension" and "union" of other questionnaires already discussed and approved by the scientific community, therefore all the variables and measures chosen to answer the research questions are validated by their utilization in other works.
The Criterion Related Validity of this work has been verified, comparing the results obtained with the results of other similar works (especially with those of Laura Swanson) and a substantial alignment was found. This comparison has been also used to give an external validity to this work, allowing to generalize the results and to extend them to all the population represented by the sample.

For what concerns the reliability, a first assessment has been pursued verifying the consistency of results between the answers of some questions strongly related. For instance, verifying the not presence of the DDD area if the plant design phase is not performed by the company.
This validation phase will be treated in more detail in a dedicated chapter, after the discussion of the data collection.

This survey is assisted type, therefore the questionnaire plays an important role, but not fundamental as in submission by mail or e-mail. In this case, the interviewer is the main channel of communication between the interviewed and the research group. Interviewers are deeply involved in the research and thus they are not neutral as a questionnaire sent by e-mail; the message that they communicate changes from interviewer to interviewer and from interview to interview. A mistaken comprehension of the questions by the interviewer introduces a systematic error (bias). Therefore, the risk of a lack of reliability and a limited validity of results is very high.
In order to reduce this risk, the first 7 interviews have been performed by two persons and one of them was the designer of questionnaires. The aim has been to develop a shared vocabulary and to make possible for each interviewer to conduct the interview alone.
These first 7 interviews led also the author to asses if all the questions were correctly understood by people interviewed (often heads of maintenance or production, able to minimize the errors introduced by a lack of knowledge of the issues treated). The reliability and the validity have been pursued, in fact, also by ensuring that the questions were comprehensible (monitoring the relevance of the answers and their uniqueness, although non using quantitative measures) and responded to the needs of the investigation.
Because of the considerable length of the questionnaire was not considered appropriate to pursue quantitative measures as the test-retest method.

5. Sample design and data collection

Quoting Cipriano Forza [12], "*Sampling is the process of selecting a sufficient number of elements from the entire population so that, by studying the sample and understanding the properties or the characteristics of the sample subjects, the researcher will be able to generalize the properties or characteristics to the population elements*".
All the difficulties related to the data collection from the entire population are overcome by the sampling. However, in order to obtain results able to represent the population, it is necessary a proper definition of the sample in terms of size and characteristics of the sample subjects.
As told before, the survey proposed was designed to be submitted to companies that perform maintenance on third parties' plants (maintenance service companies) and companies that perform maintenance on their own plants (specifying if manufacturing or process industries).
After the first seven interviews arose some problems concerning the difficulty to reach a significative number of maintenance service companies, therefore it was decided to focus all the efforts on the other type of companies.
The questionnaires are assisted type, therefore the interviewers had to move to every company involved, to submit the interview. This aspect limited the submission only to those companies close to Florence.
This first limitation was overcome, trying to conduct some interview by telephone and observing that it was possible also this type of submission. The difference was in terms of time needed: a telephone interview required a time longer than a classic on-site interview and not all the companies were disposed to give confidential information by telephone, without meet before the interviewer.
The second problem arisen from the first interviews was the acquisition of the awareness of the importance of the company industrial sector. It was observed that it was impossible to compare companies too different (this aspect will be treated in more detail in the next chapters), therefore it was decided to analyze only some industrial sectors (definition of the population frame). The first seven interviews and the knowledge of the local industrial park led the author to individuate as potential sectors the pharmacological/chemical (based especially close to the cities of Pisa and Livorno) and the paper production/manufacturing (based close to the city of Lucca) industrial sectors.
Companies of these two sectors interviewed are prevalently process industries.
The list of the companies belonging to these two sectors (the population) were obtained from the databases provided by the related trade associations: Assocarta (http://www.assocarta.it) and Farmindustria (http://www.farmindustria.it).
Assocarta and Farmindustria are two trade associations which represent all the companies in Italy that produce paper, cardboard and paper pulp and that produce pharmacological components.
According to Cipriano Forza [12], this work has proceeded designing the sample and trying to define its size.
There are many typologies of sample design, that can be grouped into two families:

- *probabilistic sampling*: sampling type where each member of the population has a probability of being selected and this probability is known;
- *non-probabilistic sampling*: sampling method where some elements of the population have no chance of selection, or where the probability of selection can't be accurately determined. Hence, because the selection of elements is nonrandom, non-

probabilistic sampling does not allow the estimation of sampling errors. These conditions place limits on how much information a sample can provide about the population.

In this work has been adopted a particular type of non-probabilistic sampling: the *convenience sampling*. In this sampling method the elements of the sample are selected, in part or in whole, at the convenience of the researcher. A sample population is selected because it is readily available and convenient.

Limits of this method lie in the fact that the researcher using such sampling methodology cannot scientifically make generalizations about the total population from this sample because it would not be representative enough. This type of sampling is most useful for pilot testing.

Despite these limits, this methodology was seemed the only possible to be adopted and the possibility to generalize the results obtained has been evaluated during the analysis of the external validity of this work (see the chapters 4 and 7).

For what concerns the size of the sample, it was decided to put limits in terms of time and not in terms of number. It was decided to collect data, performing interviews, for a maximum time of three months.

5.1 Data collection

As mentioned in the previous chapters, this work has focused exclusively on companies that perform maintenance on their own plants. At the end of the data collection the sample obtained was found to be composed by 50 companies:

- 21 companies of the production/manufacturing paper sector: both industries involved in the production of large paper rolls and industries that make the finished products as toilet paper;
- 21 companies of the chemical/pharmaceutical sector;
- 8 companies of different sectors: food, home appliance (white goods), glass production, brick production, boiler production.

Have been contacted also 5 companies that perform maintenance on third parties plants. These interviews confirmed all the problems arisen during the testing phase: a low response to the survey from this kind of companies and many difficulties in achieving a statistically significant sample. Analysis of this category should be of great interest for future works.

5.1.1 Data collection methodology

The data collection required a period of approximately three months and took place as follows:

a) The first stage consisted in the identification of the population to analyze and from which extract the sample for the different sectors studied. The list of companies that belong to the two sectors and constitute the population has been achieved thanks to the databases provided by trade associations as Assocarta (http://www.assocarta.it) and Farmindustria (http://www.farmindustria.it).

   Assocarta provided a list of all companies, based on the national territory, dealing with the paper production or manufacturing: 139 companies spread in 180 factories with a number of about 21.800 people employed.

   Farmindustria provided data about all companies, based on the national territory, dealing with pharmaceutical sector: 203 companies with 67.500 employees.

b) The second stage consisted in a first telephonic contact with the companies of the population. It was asked to speak with the production head (or maintenance head if

present) and he was informed about the purpose of the interview. If interested, a meeting was planned for the interview.
As explained before, the method adopted was the convenience sampling, therefore no limits were fixed to the number of companies interviewed. It was only decided to conduct the data collection for a period not exceeding three months.
Companies of the paper sector, contacted during this three months, were 127 (nearly all the population), while companies of the chemical/pharmaceutical sector were 73 (approximately 36% of the population).
Were also contacted 29 companies of different industrial sectors.

Table 15: companies contacted

	Companies contacted	Population
Paper sector	127	139
Chemical/pharmaceutical sector	73	203
Other sectors	29	Unknown
Total	**229**	

To encourage to participate to this survey (and also to thank for the time devoted to this project) it has been communicated to the companies contacted that, at the end of this work, they should have received indications about their degree of maturity on the issues proposed and their positioning on the global context. Therefore, companies that have participated will receive some maps showing their position with respect to the best in class in their sector, highlighting which is their current situation with regard to the issues treated.
As will be underlined later, the sensitivity and the interest shown by companies of the chemical/pharmaceutical sector have been much higher than those shown by the paper sector.
Of the 229 companies contacted by telephone, not all have agreed to participate or were found to be suitable for the study (as shown in Table 16).

Table 16: characteristics of the companies contacted

	n°	Percentage with respect to the number of companies contacted
Companies involved in the survey	**50**	**21,8%**
Companies not suitable for the analysis	69	30,1%
Outstanding interviews	54	23,6%
Companies that don't participate in surveys	17	7,4%
Companies that don't participate for other issues	34	14,8%
Total	229	100%

As anticipated, after the first telephone contact, 50 companies accepted to participate, 54 companies showed an interest, but for time and cost reasons did not participate. In general, companies based in Tuscany have been visited personally, the others, for reasons of time and resources, have been interviewed by telephone; 54 companies based outside of Tuscany accepted to be interviewed but only on-site, in the firm, and not by telephone. For this reason, the interviews have been suspended (outstanding inter-

views) in the hope that this companies would change their mind and allowed the author to carry out the interview by telephone.
Some companies (because of their production characteristics or their current economic situation) were found to be not suitable for the analysis. In more detail these companies have been those that:

- have production activities too simple (for instance companies that merely cut the paper rolls);
- have the activity stopped because of the great recession of the 2008-2010;
- have as core business not the production or manufacturing, but only the distribution (therefore they don't have production plants).

Finally, 17 companies have explicitly said that don't participate in surveys, even if submitted by the University (category "not participate in surveys"), and other 34 companies haven't agreed to participate for various reasons, such as the not-intention to divulge confidential information.
The percentage of companies that have participated is the 21,8 % of the 229 companies contacted, but without considering those of the category "not suitable for the analysis" this percentage becomes the 31,3 %. Therefore, the response to this survey can be considered quite high (most interesting considerations are possible, analyzing this percentages for every industrial sector studied).

c) The third stage was finally the assisted submission of the interviews for the 50 companies that accepted to participate.

5.1.2 Paper sector

This sector includes all those companies that produce or process paper. The companies contacted have been 127 on a total population of 139. Of these, only 82 were found to be suitable for this work:

Table 17: paper companies contacted

	n°	Percentage with respect to the population (139 companies)
Companies involved in the survey	**21**	**15,1%**
Companies not suitable for the analysis	45	32,4%
Outstanding interviews	29	20,9%
Companies that don't participate in surveys	11	7,9%
Companies that don't participate for other issues	21	15,1%
Total	127	91,4 %

For this industrial sector, the percentage of companies that have agreed to participate has been quite low, as the sensitivity shown to the issues treated. In part this behavior is influenced by the size of the companies interviewed, generally small or medium enterprises, where there are few resources dedicated to the maintenance, as well as training and specific maintenance tools. Another crucial factor was the absence in many of the companies contacted of an engineer as maintenance or production head. In those companies where the maintenance head figure was covered by an engineer, the sensibility and interest for this work has always been high.
An interesting analysis, even to understand the "weight" of the sample with respect to the total population, was performed on the basis of the revenues, as shown in Table 18.

Table 18: revenue - classification of the sample (paper sector)

Revenue class	Companies involved	Companies contacted with the exception of companies not suitable for the analysis	%
< 500.000	0	0	0,0%
500.000 - 2.500.000	1	7	14,3%
2.500.000 - 5.000.000	1	7	14,3%
5.000.000 - 25.000.000	10	33	30,3%
25.000.000 - 50.000.000	4	14	28,6%
50.000.000 - 250.000.000	0	8	0,0%
250.000.000 - 500.000.000	5	10	50,0%
> 500.000.000	0	2	0,0%
Total	21	81	

From this table it's possible to note that has been analyzed the 50% (percentage related to the sample, with the exception of companies not suitable) of companies that have annual revenues between 250 and 500 millions of euro and almost the 29% of companies with annual revenues between 25 and 50 millions of euro. These percentages are not so far from those related to the whole population, because the sample almost coincides with the population (127 vs. 139 companies) and because from this analysis have been excluded all the not suitable companies.

5.1.3 Chemical/pharmaceutical sector

This sector includes all those companies that produce or process pharmaceutical products or their components. It has been used the wider diction *chemical/pharmaceutical sector* and not only *pharmaceutical sector* because some of the companies interviewed produce the basic chemical components of the pharmaceutical products. The companies contacted have been 73 companies on a total population of 203 firms. Of these only 55 were considered suitable for this work:

Table 19: chemical/pharmaceutical companies contacted

	n°	Percentage with respect to the population (203 companies)
Companies involved in the survey	**21**	**10,3%**
Companies not suitable for the analysis	18	8,9%
Outstanding interviews	21	10,3%
Companies that don't participate in surveys	4	2,0%
Companies that don't participate for other issues	9	4,4%
Total	73	36,0%

In this case the percentage of companies involved, compared to the number of companies contacted, has been higher than the percentage of the paper sector, however the sample analyzed is less than in paper sector (73 companies against 127). Companies of the chemical/pharmaceuticals sector have been resulted more suitable for the investigation and very sensitive to the topic treated. The causes of these differences have been probably due to:

- a greater propensity to maintenance, as characteristic of this sector (ensuring the plant reliability and availability is of vital importance for these companies). Furthermore, given the importance of the products they make, many special regulations impose controls on the production process and on the traceability of the product. This context encourages and promotes approaches focused on maintenance;
- a greater availability of funds: this favors the adoption of maintenance tools and approaches, that often provide benefits in the long-term period, such as the adoption of the CMMS or the application of RCM techniques;
- a greater presence of qualified personnel involved in the production area: a strong presence of graduated engineers favor a more open-mind towards maintenance, which is no longer seen only as a cost but also as an opportunity for savings and competitive advantage.

Moreover, many chemical/pharmaceutical companies contacted that did not participate have requested information about the project and some of them were very interested to this work, but could not participate for a policy of non-disclosure of certain data (many companies of this category were American or German multinationals).

Considerations about the differences between the two sectors studied will be analyzed in more detail in the conclusions.

Classifying this sample in terms of categories of revenues:

Table 20: revenue - classification of the sample (chemical/pharmaceutical sector)

Revenue class	Companies involved	Companies contacted with the exception of companies not suitable for the analysis	%
< 500.000	0	0	0 %
500.000 - 2.500.000	0	0	0 %
2.500.000 - 5.000.000	1	2	50,0%
5.000.000 - 25.000.000	3	10	30,0%
25.000.000 - 50.000.000	2	5	40,0%
50.000.000 - 250.000.000	5	11	45,5%
250.000.000 - 500.000.000	5	11	45,5%
> 500.000.000	5	16	31,3%
Total	21	55	

As shown by the table 20, companies of the chemical/pharmaceutical sector involved in the survey spread over class of revenues higher, in average, than companies of the paper sector. Moreover, it should be noted that the 16 companies contacted with revenues over 500 million of euro represent almost the entire population of companies belonging to this category of revenue, therefore the response of 5 companies (equivalent to 31,3%) is considered quite high and results coming from the analysis of this particular category will be considered particularly significant.

6. First aim

As told in the Chapter 1.2, the two research questions have been split up into five aims. This chapter deals with the first one: assessing the current level of knowledge, implementation and automation in companies of:

- ✓ integrated methodologies, approaches and tools for maintenance (areas of the reference model);
- ✓ special purpose software;
- ✓ information flows;

Below, will be first analyzed separately the paper sector and the chemical/pharmaceutical sector, then the results will be compared with each other and with the results of the entire sample (that includes the companies of the two sectors and the eight companies of different sectors). This comparison will be very useful later, when will be analyzed in more detail the internal and external validity.

6.1 Assessment of the current level of implementation

In order to verify the current level of implementation of the reference model areas, software and information flows, the author has analyzed the answers to the following questions (see the Chapter 3.3):

- question n°26, only for what concerns the current level of implementation of the various areas of the reference model;
- question 22bis: implementation of DFR/DFA techniques;
- question 29, only for what concerns the current level of implementation of special purpose software for the areas;
- question 31, only for what concerns the current level of implementation of the information flows of the reference model.

6.1.1 Current level of implementation of the reference model areas

Paper sector

Starting from the analysis of the paper sector, for what concerns the current level of implementation of the reference model areas (question n°26), have been obtained the following results:

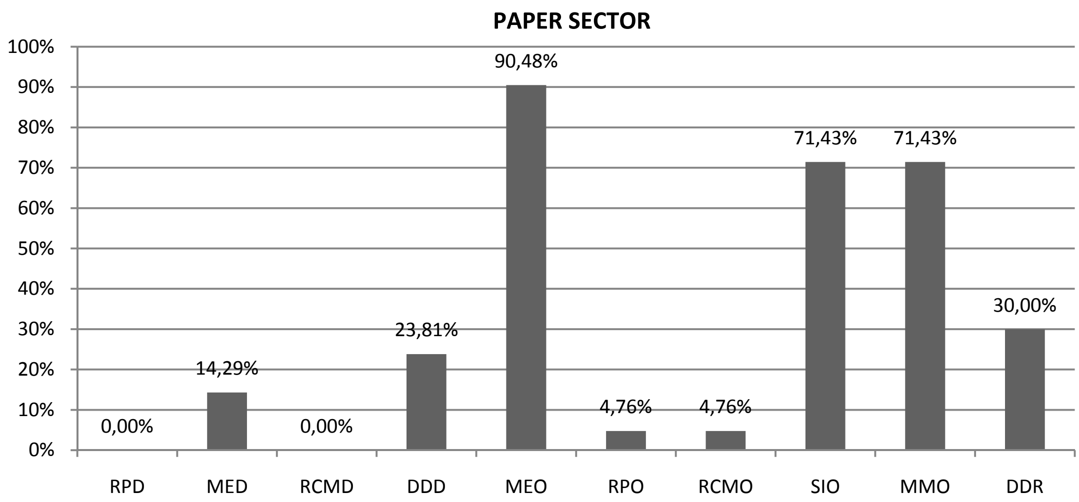


Figure 4: percentage of companies that implement the reference model areas – Paper sector (21 companies)

Table 21: number of companies that implement the following areas

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
N° of companies that implement the areas	0	3	0	9	19	1	1	15	15	9

In this work will be taken into account only those areas that are implemented by at least 5 companies. This consideration is necessary to give a statistical validity to the results.
Areas most implemented during the operational phase are the MEO, SIO and MMO, while the area most implemented during the design phase is the DDD.
The results of the questionnaire show not only if an area is implemented or not, but also the level of this implementation (Table 22):

Table 22: level of implementation of the reference model areas – the percentages refer to the 21 companies of the paper sector

	PAPER SECTOR									
	RPD	**MED**	**RCMD**	**DDD**	**MEO**	**RPO**	**RCMO**	**SIO**	**MMO**	**DDR**
Not present	**100,0%**	**85,7%**	**100,0%**	**52,4%**	9,5%	**95,2%**	**95,2%**	28,6%	28,6%	**57,1%**
Limited	0,0%	4,8%	0,0%	42,9%	19,0%	0,0%	4,8%	**38,1%**	**38,1%**	28,6%
Significant	0,0%	9,5%	0,0%	4,8%	**66,7%**	4,8%	0,0%	23,8%	28,6%	9,5%
Complete	0,0%	0,0%	0,0%	0,0%	4,8%	0,0%	0,0%	9,5%	4,8%	4,8%

Chemical/pharmaceutical sector
For what concerns this sector, the results obtained are showed below:

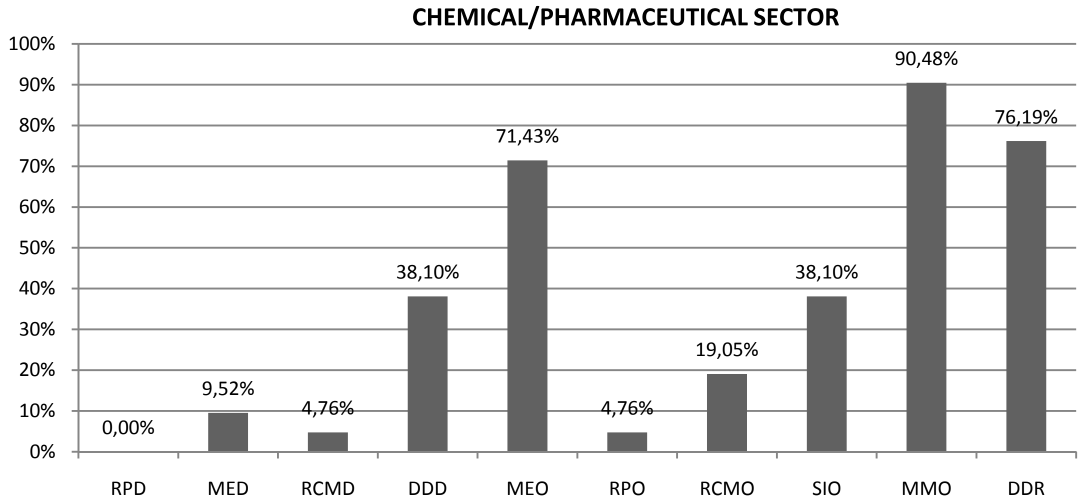


Figure 5: percentage of companies that implement the reference model areas – Chemical/pharmaceutical sector (21 companies)

Table 23: number of companies that implement the following areas

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
N° of companies that implement the areas	0	2	1	8	15	1	4	8	19	16

Areas most commonly adopted are: MMO, DDR and MEO. the SIO area is adopted, but to a lesser extent than in the paper industry. This because in the chemical/pharmaceutical sector there is a strong control on the product, greater than the control on the process (as in the paper sector).
This is justified also by the high level of implementation of the DDR area present in this sector (combined with a medium level of implementation of the DDD area): the particularity of the pharmaceutical products or the need to keep secret their composition require that the design of the plant is carried out in-house (this is also due to an high customization of assets, bigger than in the paper sector).

Table 24: level of implementation of the reference model areas – the percentages refer to the 21 companies of the chemical/pharmaceutical sector

	CHEMICAL/PHARMACEUTICAL SECTOR									
	RPD	**MED**	**RCMD**	**DDD**	**MEO**	**RPO**	**RCMO**	**SIO**	**MMO**	**DDR**
Not present	**100,0%**	**90,5%**	**95,2%**	**61,9%**	28,6%	**95,2%**	**81,0%**	**61,9%**	9,5%	23,8%
Limited	0,0%	0,0%	0,0%	14,3%	9,5%	0,0%	4,8%	9,5%	9,5%	**38,1%**
Significant	0,0%	9,5%	4,8%	14,3%	**52,4%**	0,0%	9,5%	9,5%	**38,1%**	28,6%
Complete	0,0%	0,0%	0,0%	9,5%	9,5%	4,8%	4,8%	19,0%	42,9%	9,5%

From this first analysis on the level of implementation, areas most implemented resulted the following:DDD, MEO, SIO, MMO and DDR.
As can be seen also considering the whole sample (50 companies):

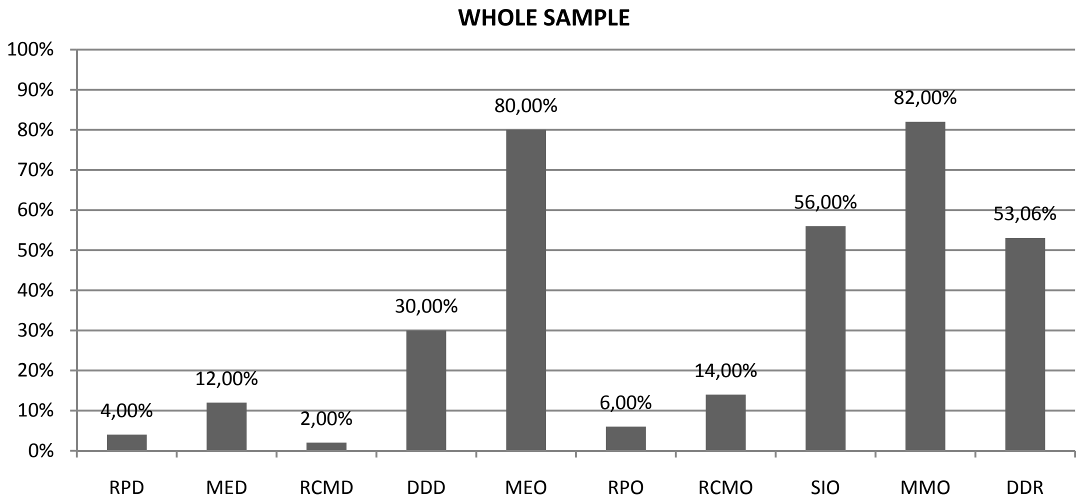


Figure 6: percentage of companies that implement the reference model areas – whole sample (50 companies)

Table 25: number of companies that implement the following areas

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
N° of companies that implement the areas	2	6	1	19	40	3	7	28	41	29

Below, each of the five most implemented areas is analyzed in more detail, for each industrial sector and also for the whole sample.

The 5 most implemented areas

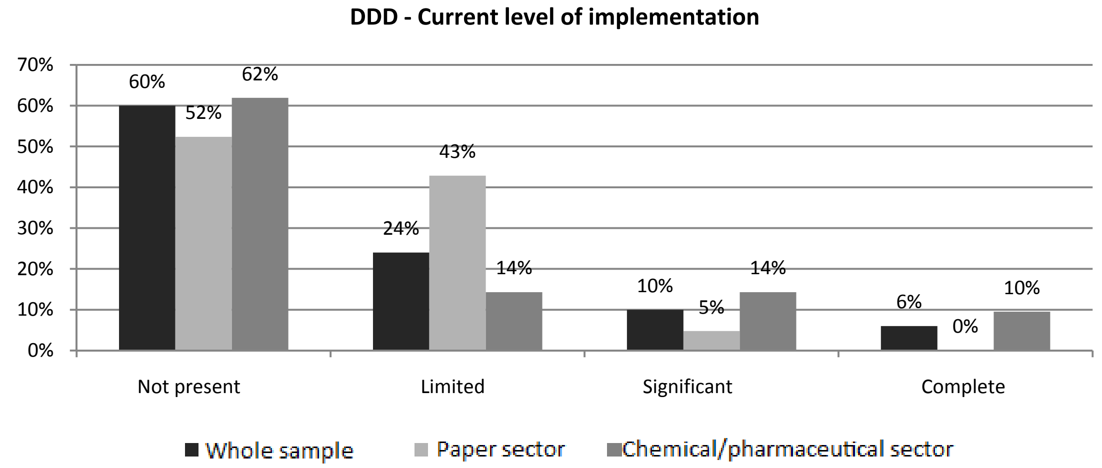


Figure 7: current level of implementation of the area DDD

Not considering the "Not present" level, in the paper sector the adoption of the DDD area is limited, while in the chemical/pharmaceutical is significant or complete. However, the degree of implementation of this area is quite low for both sectors.

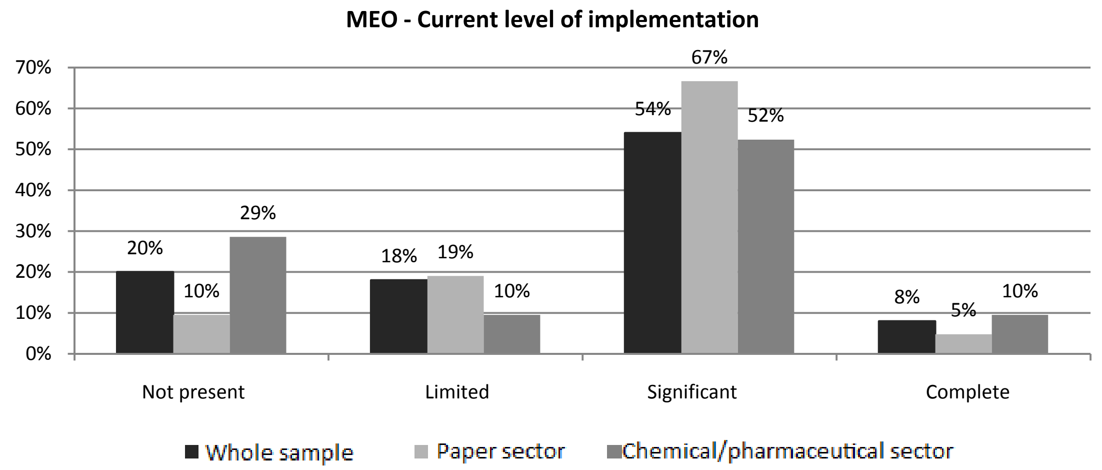


Figure 8: current level of implementation of the area MEO

The level of implementation of the MEO area is prevalently significant for both sectors.

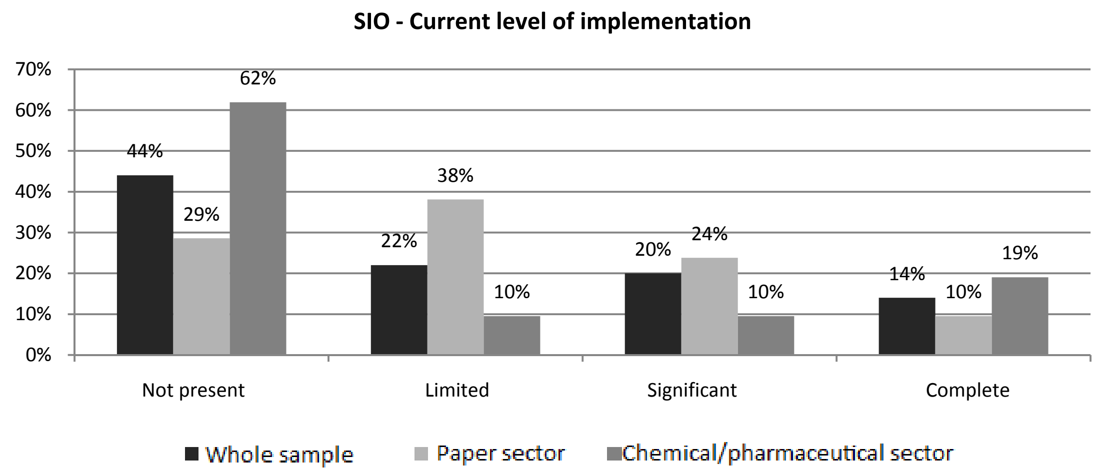


Figure 9: current level of implementation of the area SIO

The SIO area, as highlighted before, is implemented more in the paper sector, however, when it is adopted by the chemical/pharmaceutical sector, it is implemented prevalently at a complete level.

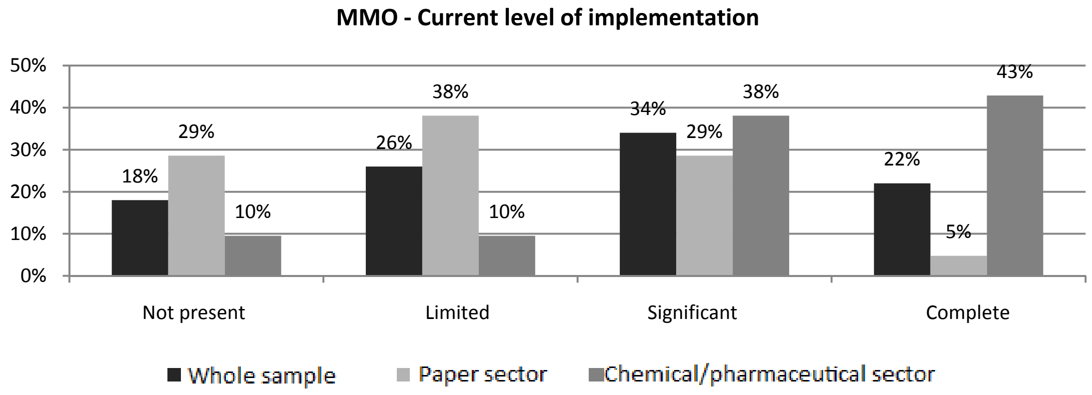


Figure 10: current level of implementation of the area MMO

For both sectors the MMO area is heavily adopted, but the level of implementation is much higher in the chemical/pharmaceutical industry. It will be seen in the next chapters that the adoption of this area is strongly linked to factors that characterize the chemical/pharmaceutical sector.

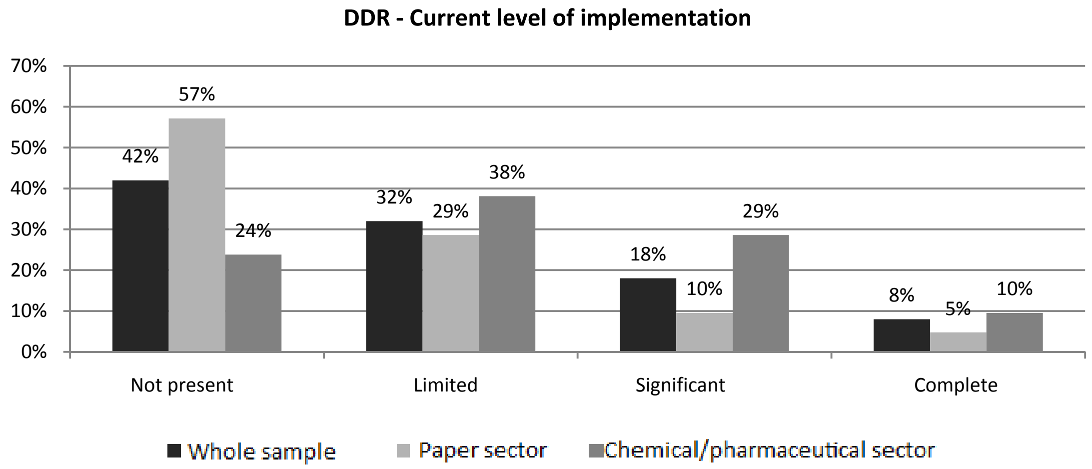


Figure 11: current level of implementation of the area DDR

The DDR area is mostly adopted by the chemical/pharmaceutical sector and this result is consistent with the result obtained for the DDD area (the two areas are closely linked).
It is also possible to verify the implementation of the DDR and DDD areas, by analyzing the answers to the question 22 bis:

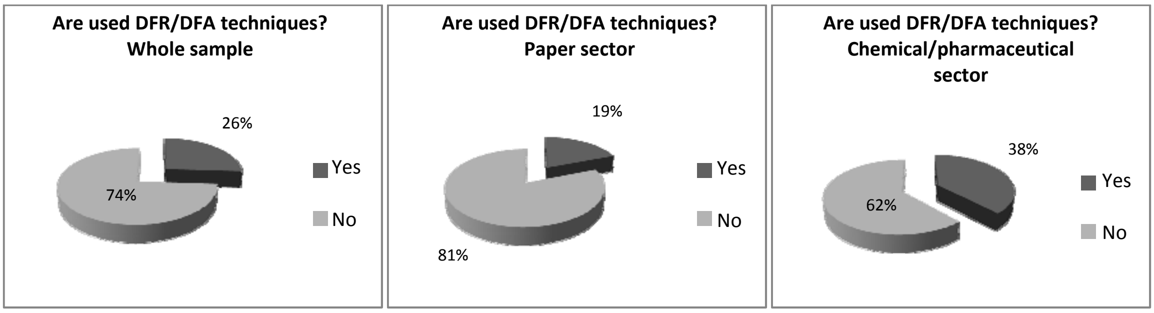


Figure 12: implementation of Design For Reliability (DFR)/ Design For Availability (DFA) techniques

In the chemical/pharmaceutical sector the adoption of the DDD and DDR areas is most significative than in the paper industry (that have a bigger implementation of the DDD area, but at a limited level), and this is confirmed by the results of question 22 bis: the adoption of techniques to improve the plant reliability and availability during the design phase is proportional to the implementation of DDR and DDD areas (at significant and complete levels).
Another interesting analysis is the assessment of the level of implementation of the various areas, not only as function of the industrial sector but also as function of the size of companies in terms of annual revenue, splitting up the sample in small companies (up to 5 million of euro), medium-size companies (up to 50 million of euro) and large enterprises (more than 500 million of euro).

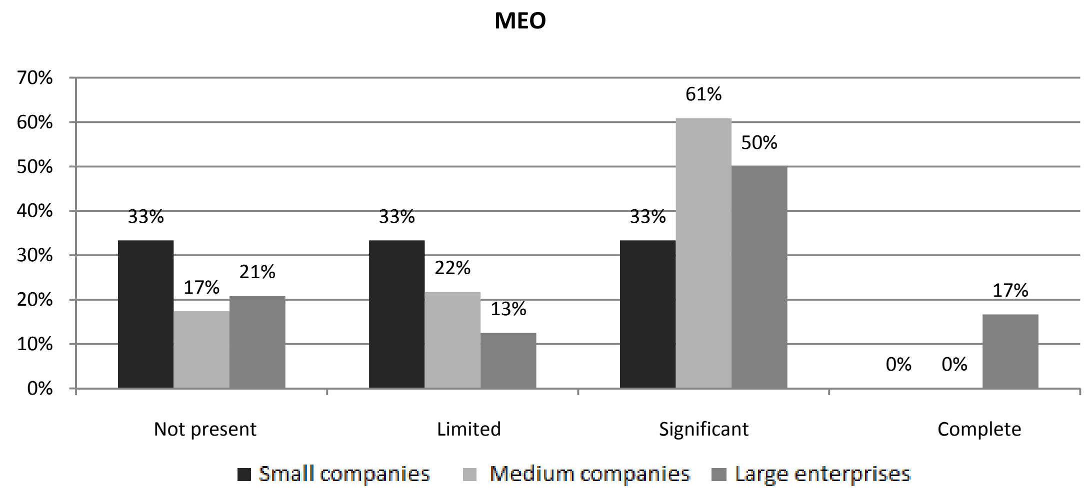


Figure 13: current level of implementation of the area MEO – revenue classification

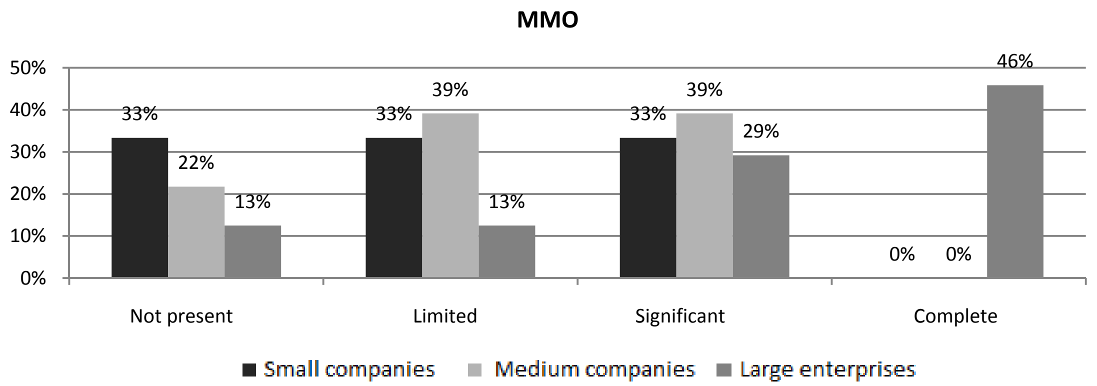


Figure 14: current level of implementation of the area MMO – revenue classification

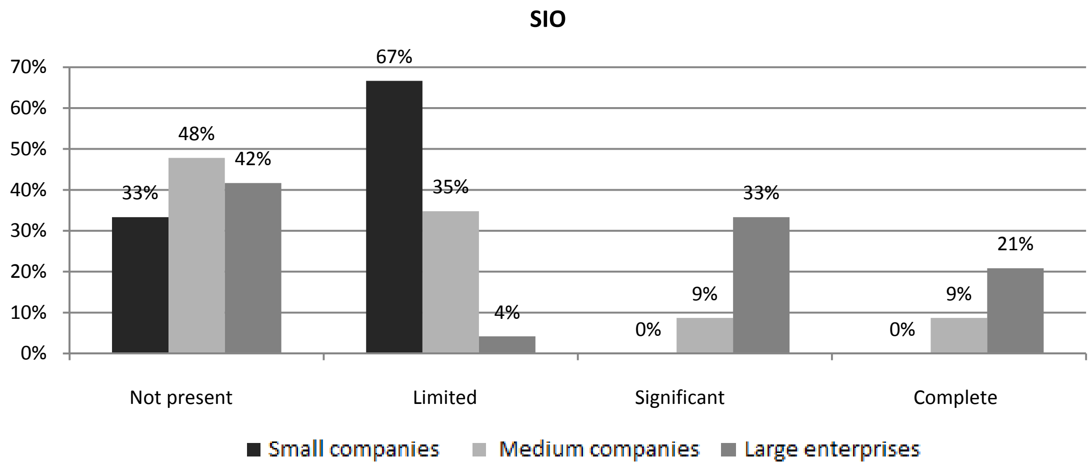


Figure 15: current level of implementation of the area SIO – revenue classification

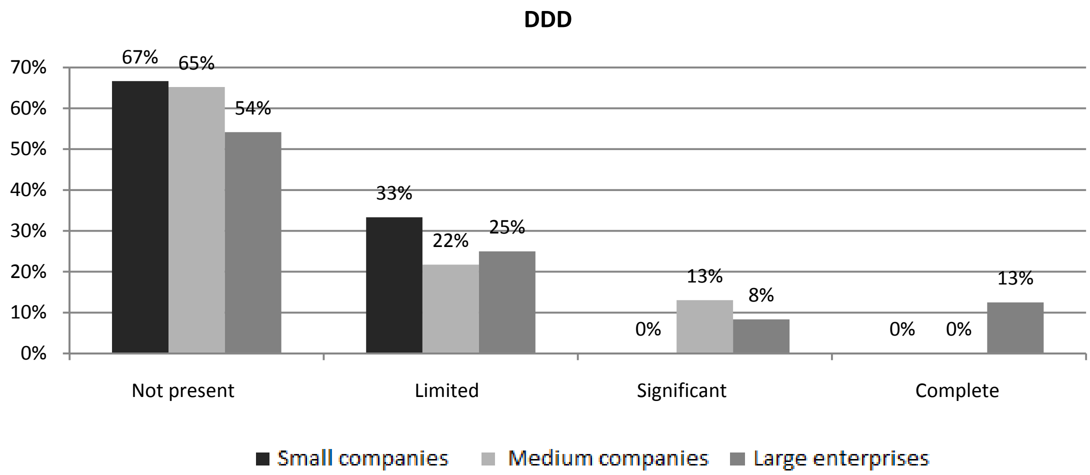


Figure 16: current level of implementation of the area DDD – revenue classification

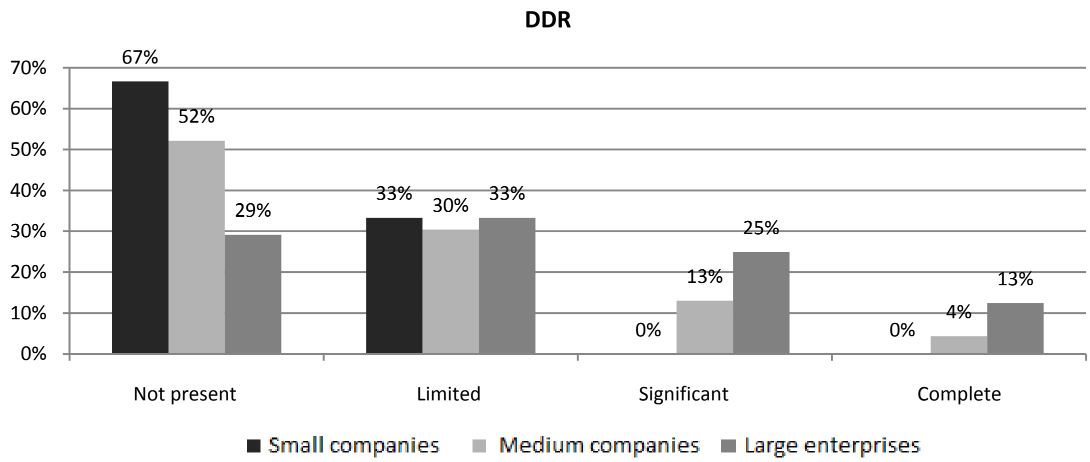


Figure 17: current level of implementation of the area DDR – revenue classification

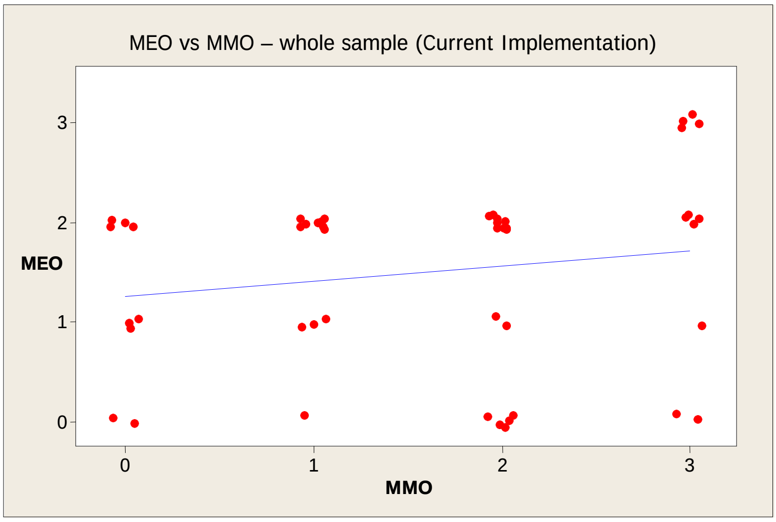
As expected, the level of implementation of these areas is proportional to the size of companies (in terms of revenues). These considerations will be treated in more detail in the chapter 9.

Simultaneous presence of different areas

To answer the first point of the first aim and assess the level of integration of these areas, it was considered appropriate to carry out a vertical analysis (an analysis performed to evaluate the simultaneous presence of different areas along the vertical axis of the reference model): this analysis has identified the simultaneous presence of several areas that operate on the same phase of plant lifecycle.

The couple of areas simultaneously present analyzed have been: MEO+MMO, SIO+MMO, SIO+MEO e MED+DDD. To conduct this analysis the author adopted scatterplots graphs with trend lines.

Couple MEO+MMO:



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 18: Scatterplot MEO vs MMO (whole sample)

In the above picture the trend line (blue line) has a slight positive slope. This indicates that to a greater implementation of the MMO area correspond a greater implementation of the MEO area.

The trend line provides only an indicative information because it was not found a statistically significant correlation between the MEO and MMO areas (as will be shown later in Tables 26, 27 and 28). In fact, using the Minitab 14 software, it results that the Pearson correlation coefficient is equal to 0.174 (weak correlation) and the P-value is 0.226 (far from the significance level adopted: 5%).

In this regard, below are reported the definitions of the Pearson correlation and the P-value:

- *Pearson product-moment correlation coefficient*: given two variables X and Y, the Pearson correlation coefficient is defined by the following equation:

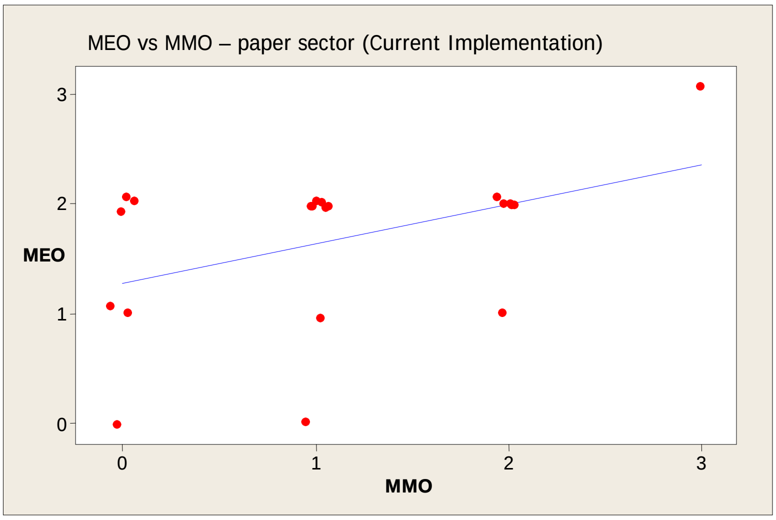
$$\rho_{XY} = \frac{\sigma_{XY}}{\sigma_X \sigma_Y}$$

where σ_{XY} is the covariance of the two variables, while σ_X and σ_Y are their standard deviations. The Pearson coefficient can assume values between -1 and +1: if negative, the two variables X and Y are inversely correlated or negatively correlated, while if positive, these two variables are positively correlated.

Concerning the interpretation of the Pearson coefficient it can be asserted that, if the coefficient is greater than 0.7 (or less than -0.7) the correlation is significant, if the coefficient is between 0.3 and 0.7 the correlation is moderate, if the coefficient is between 0.3 and 0.1 the correlation is weak, if the coefficient is lower than 0.1 the correlation is null. Value of 1 implies that a linear equation describes the relationship between X and Y perfectly, with all data points lying on a line for which Y increases as X increases. A value of −1 implies that all data points lie on a line for which Y decreases as X increases. A value of 0 implies that there is no linear correlation between the variables.

- *P-value*: the p-value of a statistical hypothesis testing indicates the probability of obtaining a result equal to or more extreme than the one observed, assuming that the null hypothesis H_0 is true (the hypothesis that test wants to verify; in this case the null hypothesis is: "*the levels of implementation of the two areas are not related*"). On the same hypothesis testing, p-value indicates the minimum level of significance for which the null hypothesis is rejected. Null hypothesis is rejected if the test gives a p-value less than the significance level of the test (in this analysis 5%), and is accepted otherwise.
  Therefore, if the p-value of a test is 3% (0.03) and the significance level assumed is 5%, then the null hypothesis is rejected and it's possible to assert that between the two variables there is a correlation.

Distinguishing between the paper sector and the chemical/pharmaceutical sector, scatterplots show different behaviors:

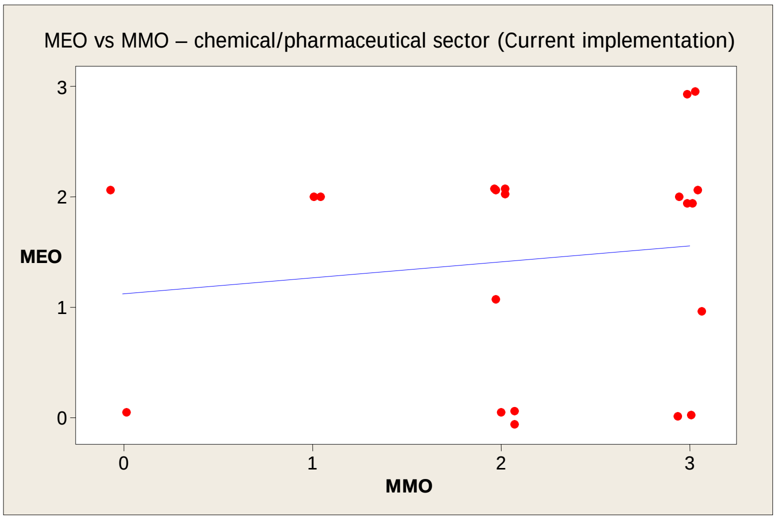


Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 19: Scatterplot MEO vs MMO (paper sector)

Also in this case is confirmed the upward trend of the trend line slope, but there is also a moderate significant correlation between the two levels of implementation: the Pearson correlation coefficient is 0.283 and the P-value is 0.048.
However, it must be noted that, apart from a single company, the other companies never achieve a level of implementation complete of the MEO area or of the MMO area. Moreover, it must be noted that where a CMMS is implemented, it's almost always implemented the MEO area (not vice versa). This can be justified considering that many of these companies do not make a proper maintenance planning: they merely make meetings where they decide, basing on experience, how often and on which components perform maintenance.

For what concerns the chemical/pharmaceutical sector:

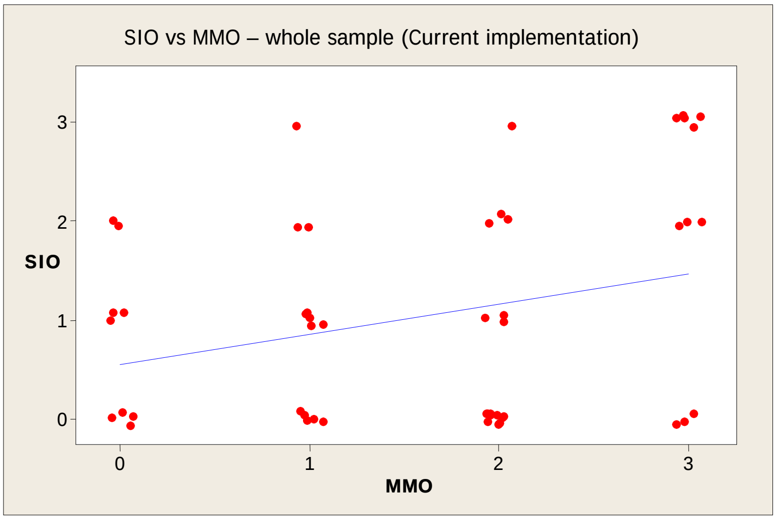


Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 20: Scatterplot MEO vs MMO (chemical/pharmaceutical sector)

In this case the trend line rises slightly and there isn't a statistically significant correlation between the two variables (Pearson correlation coefficient equal to 0.137 and P-value equal to 0.554). However, it is interesting to see how companies of this sector are positioned on implementation levels (almost always significant or complete) higher than those of the paper industry.

<u>Couple SIO+MMO:</u>



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 21: Scatterplot SIO vs MMO (whole sample)

The correlation between the implementation of the MMO area and the implementation of the SIO area is positive, but there isn't a predominant positioning; companies, in fact, are distributed fairly evenly in the chart. To make most interesting considerations should be analyzed the two sectors separately.

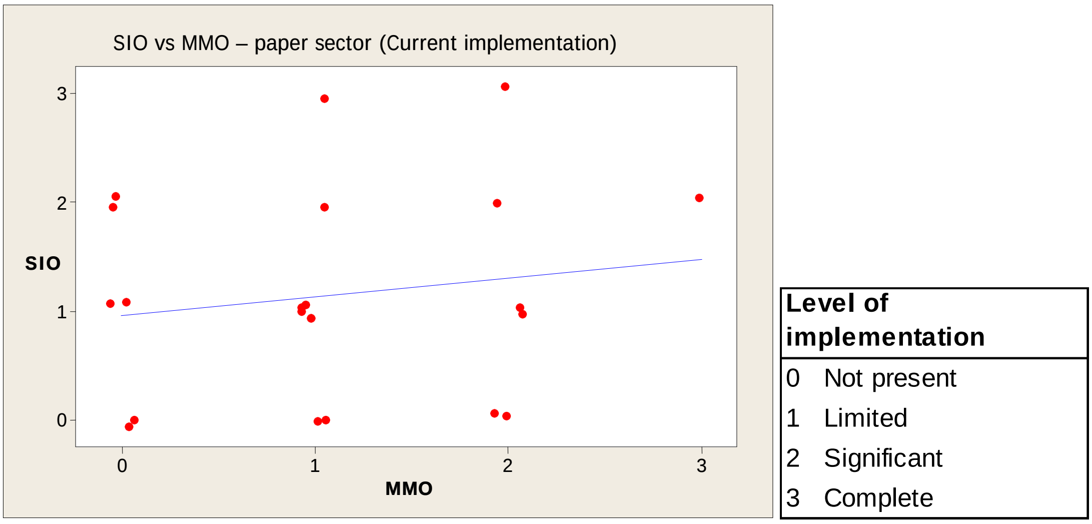


Figure 22: Scatterplot SIO vs MMO (paper sector)

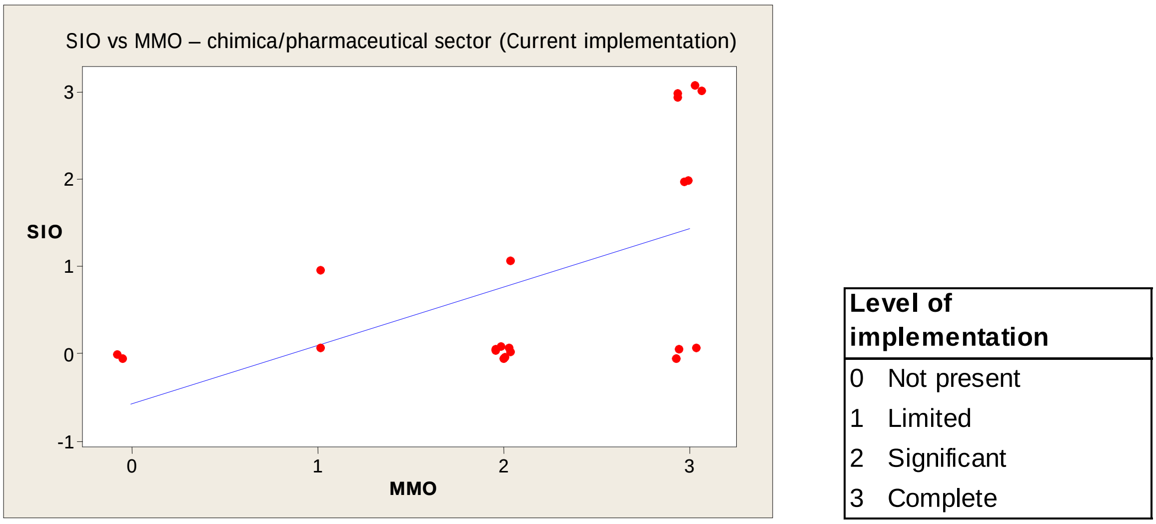


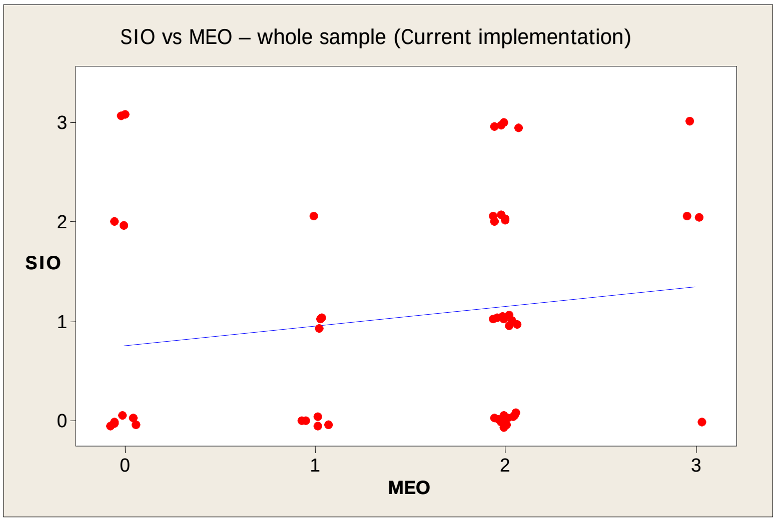
Figure 23: Scatterplot SIO vs MMO (chemical/pharmaceutical sector)

Analyzing the two sectors, it's possible to note different behaviors: in the paper sector companies are distributed fairly evenly (there isn't in fact a statistically significant correlation: the Pearson correlation coefficient is 0.158 and the P-value is 0.493), but with a higher concentration at a level of implementation low for both areas.

The scatterplot for the chemical/pharmaceutical sector highlights a positive slope of the trend line (Pearson correlation coefficient equal to 0.522 and its P-value equal to 0.015). It is also evident a more marked concentration of companies at high levels of implementation, especially for the MMO area.

Therefore, even if companies of this sector that adopt the SIO area are in number less than the companies of the paper sector, when they do this, it is observed also a strong presence of tools for maintenance management (CMMS).

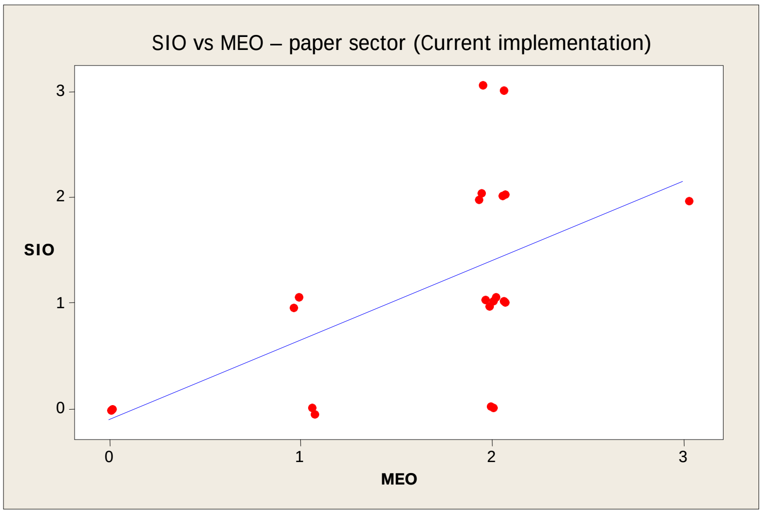
Couple SIO+MEO:



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

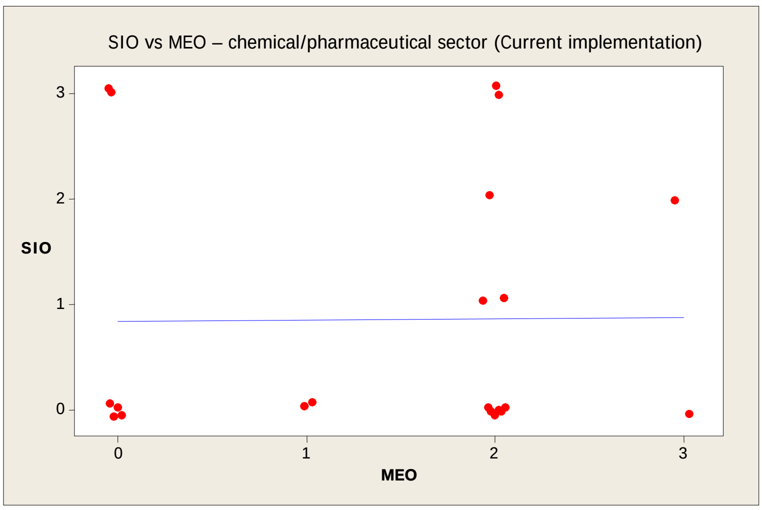
Figure 24: Scatterplot SIO vs MEO (whole sample)

Few consideration emerge from the analysis of the entire sample. Considering the two industrial sectors separately:



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 25: Scatterplot SIO vs MEO (paper sector)



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 26: Scatterplot SIO vs MEO (chimica/pharmaceutical sector)

In the paper sector there is a strong positive correlation (Pearson correlation coefficient equal to 0.568 and P-value equal to 0.007). This means that high levels of implementation of the SIO area correspond to high levels of implementation of the MEO area.
Completely different is the situation for the chemical/pharmaceutical sector, where the correlation between the two areas is almost non-existent (Pearson correlation coefficient equal to 0.011 and P-value equal to 0.961).
It is also interesting to note how the results obtained in the analysis of the couple SIO+MMO are exactly opposite to those obtained for the couple SIO+MEO: the first couple is strongly correlated in the chemical/pharmaceutical sector and not in the paper sector, the second couple is strongly correlated in the paper sector and not in the chemical/pharmaceutical.
This different behavior may be explained by the fact that, in percentage, companies of the chemical/pharmaceutical sector implement the MMO area more than those of the paper sector (90.48% against 71.43%) and recognize the central role played by the CMMS in data collection. The vice versa is for the area MEO (71.43% of companies of the chemical/pharmaceutical sector, against 90.48% of companies of the paper sector).

Couple MED+DDD:

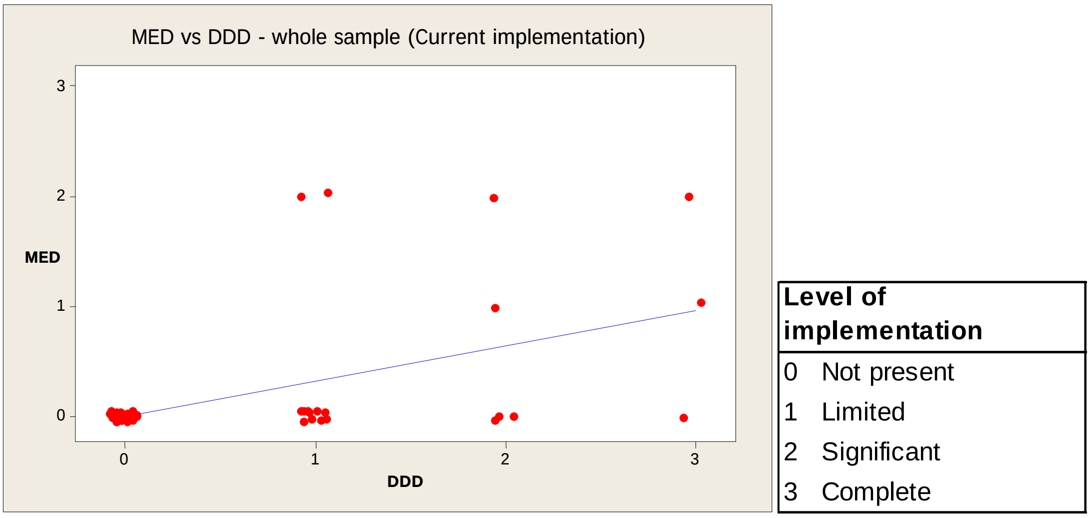
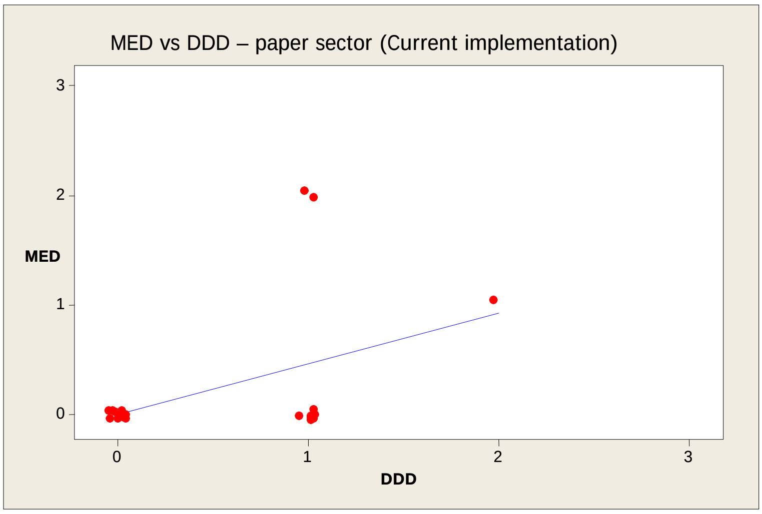


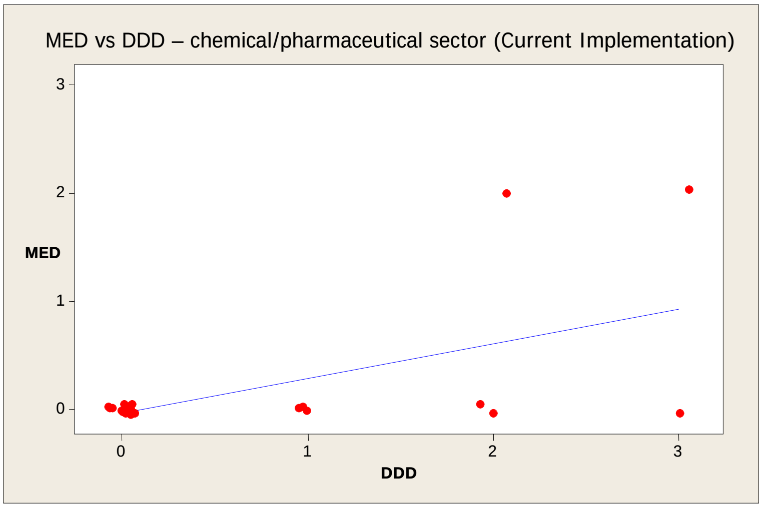
Figure 27: Scatterplot MED vs DDD (whole sample)

MED and DDD are both areas of the design phase. Areas of this phase are, in general, less implemented than those of the operational phase: this is confirmed by the presence of a large number of companies at 0 level of implementation. Excluding these records, it is noted that the other companies are positioned on low or medium level of implementation, especially for the MED area.



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 28: Scatterplot MED vs DDD (paper sector)



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 29: Scatterplot MED vs DDD (chemical/pharmaceutical sector)

For the two industrial sectors considered, the results are similar to those of the whole sample: very strong presence at the 0 level and very few companies that implement the MED area. It is observed also an higher level of implementation of the DDD area in the chemical/pharmaceutical sector.

The choice of the couples MEO+MMO, SIO+MMO, SIO+MEO and MED+DDD has been dictated by the common sense, considering their different functionalities. A more detailed analysis has been made through the use of software Minitab14, which has calculated the Pearson correlation coefficient and the P-value for each possible couple of areas (see the following tables, where the Pearson correlation coefficient is the value at the top, while the P-value is the value at the bottom).
Five different analysis have been carried out, basing on the industrial sector (whole sample, paper sector and chemical/pharmaceutical sector) and on the size (medium and large companies). The results are shown in the following tables, the boxes with the values in bold are those that show a statistically significant correlation with p-value less than 5% (significance level adopted).

Table 26: Pearson correlation coefficient - areas (whole sample)

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO
MED	0,108 0,454								
RCMD	-0,029 0,841	**0,455** **0,001**							
DDD	**0,43** **0,002**	**0,507** **0**	**0,381** **0,006**						
MEO	0,113 0,433	0,236 0,099	0,238 0,096	0,237 0,098					
RPO	-0,048 0,743	**0,604** **0**	**0,798** **0**	**0,317** **0,025**	0,172 0,231				
RCMO	0,239 0,095	**0,305** **0,031**	**0,607** **0**	0,261 0,067	0,239 0,094	**0,511** **0**			
SIO	0,272 0,056	0,052 0,722	-0,136 0,347	**0,323** **0,022**	0,162 0,26	-0,009 0,953	0,071 0,625		
MMO	0,08 0,58	0,104 0,472	0,196 0,172	0,273 0,055	0,174 0,226	0,053 0,713	**0,326** **0,021**	**0,283** **0,046**	
DDR	**0,337** **0,017**	**0,326** **0,021**	**0,311** **0,028**	**0,598** **0**	0,163 0,259	0,141 0,328	**0,385** **0,006**	**0,29** **0,041**	**0,521** **0**

Table 27: Pearson correlation coefficient - areas (paper sector)

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO
MED	* *								
RCMD	* *	* *							
DDD	* *	**0,45** **0,041**	* *						
MEO	* *	0,183 0,428	* *	0,303 0,181					
RPO	* *	**0,646** **0,002**	* *	0,181 0,431	0,105 0,652				
RCMO	* *	-0,087 0,707	* *	-0,2 0,386	**-0,523** **0,015**	-0,05 0,83			
SIO	* *	0,273 0,231	* *	0,296 0,193	**0,568** **0,007**	0,204 0,376	-0,272 0,233		
MMO	* *	-0,133 0,566	* *	0,089 0,701	**0,436** **0,048**	-0,282 0,215	-0,282 0,215	0,158 0,493	
DDR	* *	0,176 0,445	* *	0,403 0,07	0,185 0,423	-0,164 0,477	-0,164 0,477	0,129 0,579	**0,44** **0,046**

Table 28: Pearson correlation coefficient - areas (chemical/pharmaceutical sector)

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO
MED	* *								
RCMD	* *	**0,689** **0,001**							
DDD	* *	**0,562** **0,008**	**0,496** **0,022**						
MEO	* *	0,185 0,423	0,35 0,12	0,118 0,609					

RPO	* *	**0,689** **0,001**	1 *	**0,496** **0,022**	0,35 0,12				
RCMO	* *	0,43 0,052	**0,694** **0**	0,18 0,435	0,426 0,054	**0,694** **0**			
SIO	* *	-0,23 0,315	-0,159 0,492	0,235 0,304	0,011 0,961	-0,159 0,492	0,007 0,977		
MMO	* *	0,296 0,193	0,204 0,376	0,288 0,206	0,137 0,554	0,204 0,376	0,291 0,2	**0,522** **0,015**	
DDR	* *	**0,445** **0,043**	0,428 0,053	**0,574** **0,007**	0,044 0,849	0,428 0,053	**0,435** **0,049**	**0,459** **0,036**	**0,456** **0,038**

Table 29: Pearson correlation coefficient - areas (medium enterprises)

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO
MED	-0,045 0,837								
RCMD	* *	* *							
DDD	**0,454** **0,029**	**0,454** **0,029**	* *						
MEO	-0,12 0,584	0,156 0,476	* *	0,254 0,242					
RPO	* *	* *	* *	* *	* *				
RCMO	-0,045 0,837	-0,045 0,837	* *	-0,143 0,516	-0,397 0,061	* *			
SIO	0,279 0,197	0,05 0,821	* *	0,287 0,184	0,374 0,078	* *	-0,179 0,413		
MMO	-0,049 0,825	0,232 0,288	* *	0,087 0,693	0,168 0,444	* *	-0,329 0,125	-0,069 0,753	
DDR	0,325 0,131	**0,574** **0,004**	* *	**0,522** **0,011**	0,135 0,54	* *	-0,173 0,429	0,299 0,166	0,348 0,103

Table 30: Pearson correlation coefficient - areas (large companies)

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO
MED	0,173 0,419								
RCMD	-0,043 0,84	**0,45** **0,027**							
DDD	**0,443** **0,03**	**0,525** **0,008**	**0,443** **0,03**						
MEO	0,289 0,171	0,244 0,251	0,289 0,171	0,207 0,332					
RPO	-0,072 0,737	**0,594** **0,002**	**0,795** **0**	0,347 0,097	0,189 0,376				
RCMO	0,372 0,074	0,248 0,243	**0,613** **0,001**	0,291 0,167	0,346 0,098	**0,484** **0,017**			
SIO	0,286 0,175	-0,046 0,833	-0,229 0,281	0,286 0,175	-0,035 0,872	-0,095 0,658	0,013 0,951		
MMO	0,184 0,389	-0,093 0,665	0,184 0,389	0,325 0,121	0,152 0,479	-0,083 0,698	0,329 0,117	0,375 0,071	
DDR	0,374 0,072	0,228 0,283	0,374 0,072	**0,643** **0,001**	0,163 0,447	0,101 0,638	**0,468** **0,021**	0,218 0,307	**0,506** **0,012**

The null hypothesis H_0 for the p-value has been: "*the levels of implementation of the two areas are not related*". A p-value less than 5% (significance level adopted) leads to reject it. Were therefore taken into account only those combinations with a p-value less than 0.05.

Results concerning the whole sample show that the most significant couples in addition to those already examined are:

- SIO with DDD (expected result, because many process control systems must be planned, at least in part, during the design phase of the plant);
- MMO with RCMO and SIO (these areas are strongly linked and depend with each other. It is clear the central role played by the CMMS for data collection).

Results show that there are other couples significantly correlated. However, for these couples the number of companies is less than 5, therefore it is difficult, from a statistical point of view, generalize these correlations. These couples are:

- RCMD with MED (expected result given the strong link between these two elements: RCMD needs the information provided by the maintenance engineering of the design phase);
- DDD with RPD, MED and RCMD (evident in this case is the link between the areas of the design phase and the DDD area);
- RPO with MED, RCMD and DDD (also for these elements is evident the link between the reliability prediction and the various areas of the design phase);
- RCMO with MED, RCMD and RPO (companies that adopt the RCM during the design phase, then use it also during the operational phase; moreover, there is a direct correlation with the area of reliability prediction, which provides important information for the definition of the maintenance policies to adopt);
- DDR with RPD, MED, RCMD, DDD, RCMO, SIO and MMO (this result highlights how the presence of the area related to the revamping is highly dependent on the presence of the design phase areas, but also how it is necessary for DDR receiving data and information from the process control, CMMS and RCM).

The number of significant correlations is lower in the paper sector and in the medium enterprises. Greater coherence is present in the chemical/pharmaceutical sector and in large companies. This is another proof of how the industrial sector and the availability of funds are important drivers for the adoption of the various areas of the reference model.

Methodologies adopted for the Maintenance Engineering

Analyzing the results of question 26 (see the attached questionnaire), it has been assessed if MED and MEO areas (areas related to the Maintenance Engineering during the design and operational phases) are implemented or not and, if so, at what level of implementation. To identify which methodologies are used for the Maintenance Engineering it is necessary to analyze the question 27. The figure below shows the results referred to the whole sample.

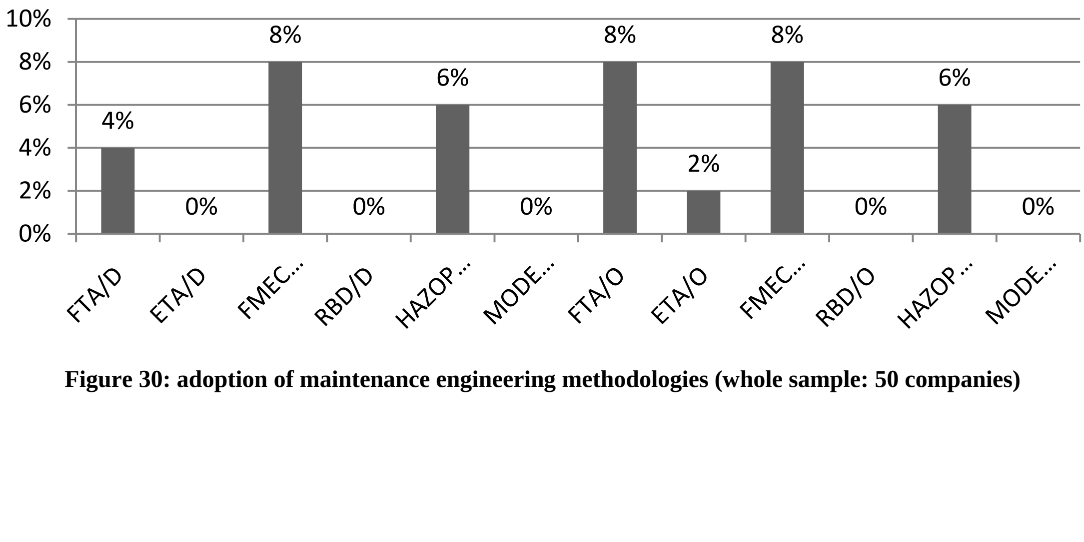


Figure 30: adoption of maintenance engineering methodologies (whole sample: 50 companies)

The level of adoption of all these techniques is very low. Those most used are the FMECA (adopted by 4 companies both in the design and operational stage) and the FTA (4 companies in the operational and 2 in design phase).
Comparing the paper industry with the chemicals/pharmaceuticals companies:

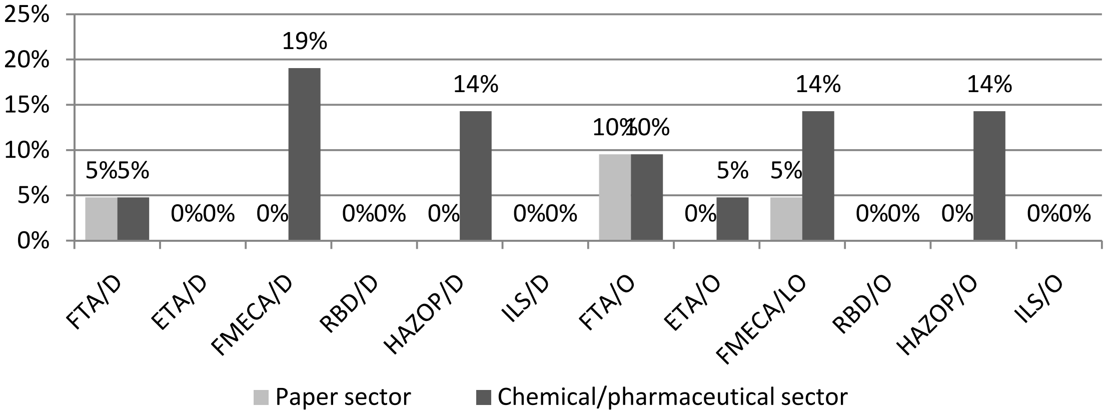


Figure 31: adoption of maintenance engineering methodologies paper sector (21 companies) and chemical/pharmaceutical sector (21 companies)

It is evident how these techniques are more adopted in the chemical/pharmaceutical sector. In particular, the FMECA during the design phase is adopted by 4 companies (almost the 20% of the chemical/pharmaceutical companies interviewed).
The low values of implementation can be, in part, explained by the fact that in the questionnaire was asked the explicit application of such techniques (some companies adopt them, but not in a formal way).

6.1.2 Current level of implementation of special purpose software

In this section the current level of implementation of special purpose software for the different areas of the model will be analyzed (question n°29).
The figure below shows the companies (as a percentage of the whole sample of 50 firms) that use specialized software in different areas. The level of implementation is not specified, because this issue will be treated in more detail in the Chapter 6.2.

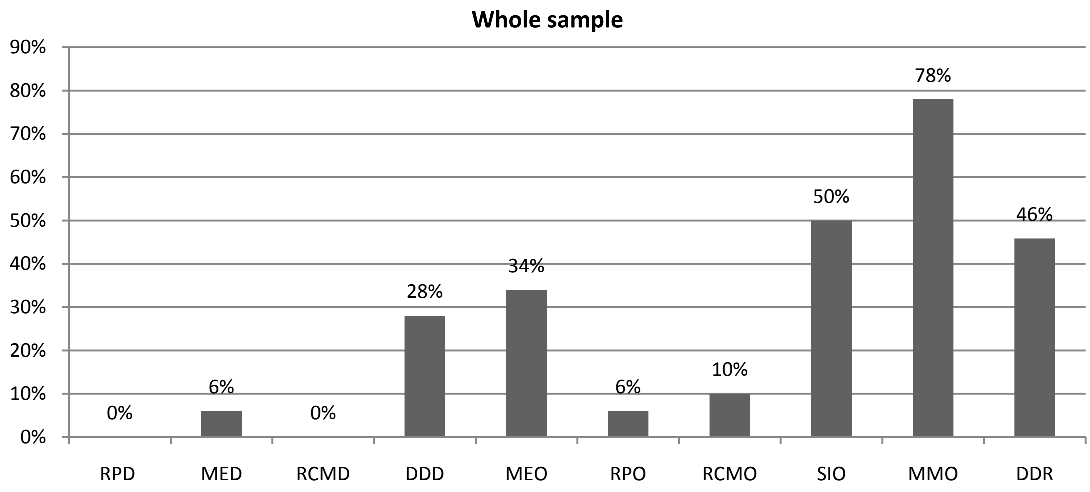


Figure 32: special purpose software adoption (whole sample)

Special purpose software are more implemented for the MMO (CMMS), DDR and SIO areas. Comparing the two industrial sectors:

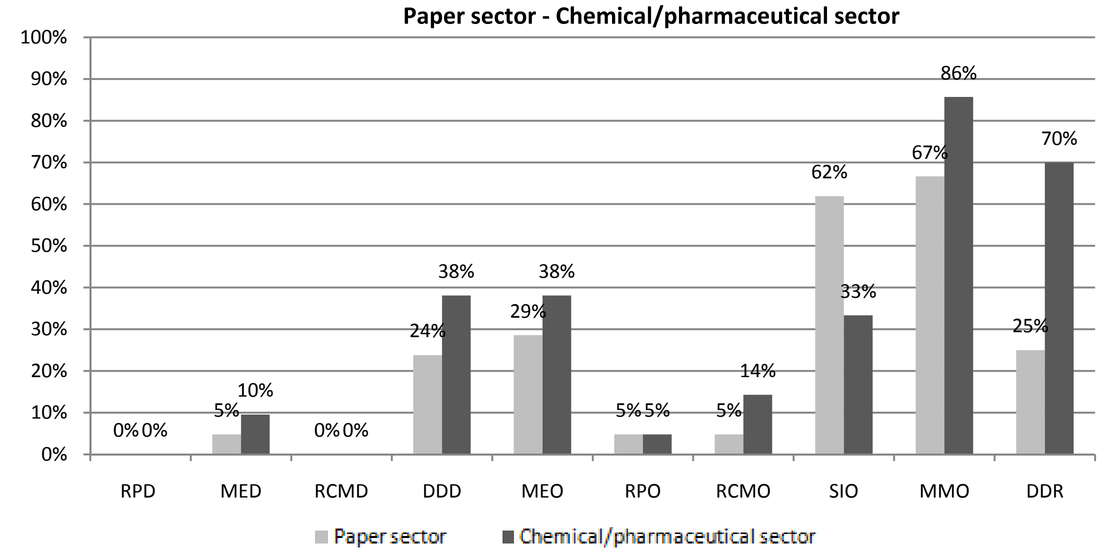


Figure 33: special purpose software adoption (paper sector and chemical/pharmaceutical sector)

In average, the chemical/pharmaceutical sector implement software in almost all areas more extensively than in the paper industry; only exception is for the SIO area (because the adoption of this area by chemical/pharmaceutical companies is limited).

6.1.3 Current level of implementation of information flows

Through the question n°31 it has been analyzed the level of implementation of the information flows between the areas of the reference model. The following figure shows the results referred to the entire sample (50 companies).

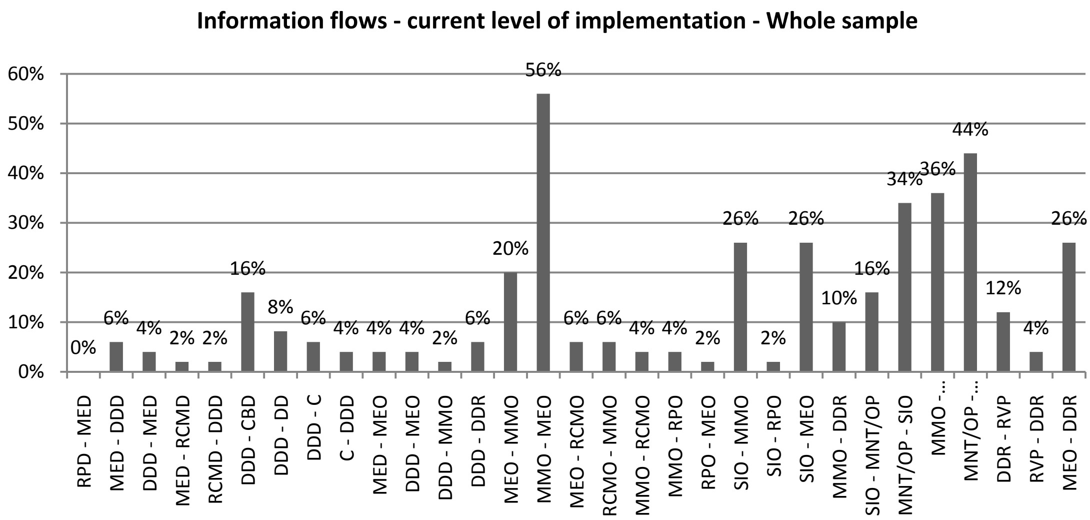


Figure 34: current implementation of the information flows (whole sample)

Information flows more implemented are MMO-MEO, MMO-MNT/OP, MNT/OP-MMO, MNT/OP-SIO. Not surprisingly, these flows correspond to the most implemented areas (MMO, MEO and SIO). Comparing the two industrial sectors:

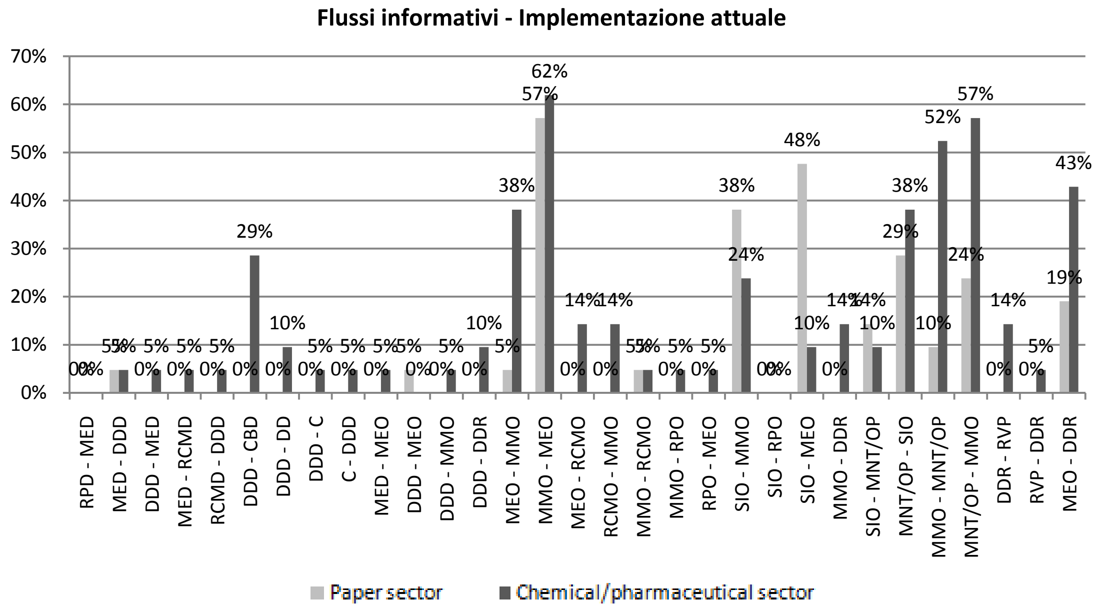
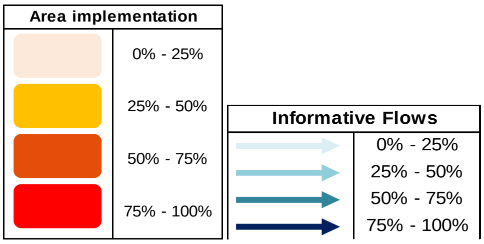


Figure 35: current implementation of the information flows (paper sector and chemical/pharmaceutical sector)

As highlighted by the graph, the adoption of information flows in the paper sector is lower than in the other sector. In part this difference can be explained by the fact that, on average, paper companies have an implementation of the areas lower than chemical/pharmaceutical companies. In the following chapters it will be studied in more depth the difference between the level of implementation of the areas and the presence of the information flow.
The differences between the two sectors are more pronounced in the design phase, where information flows in the paper sector are almost totally not implemented; these differences decrease during the operational phase.
The only two exceptions are the SIO-MMO and the SIO-MEO flows because of the most intensive implementation of the SIO area in the paper sector.

6.1.4 Current level of implementation of areas and flow: a graphical view

The results presented in sections 6.1.1 and 6.1.3, concerning the current level of implementation of the areas of the reference model and the related information flows, are displayed in the three following figures (greater is the intensity of the color and higher is the level implementation).
The first figure refers to the entire sample interviewed (50 companies), while the next two refer to the paper sector and the chemical/pharmaceutical sector (21 companies each).



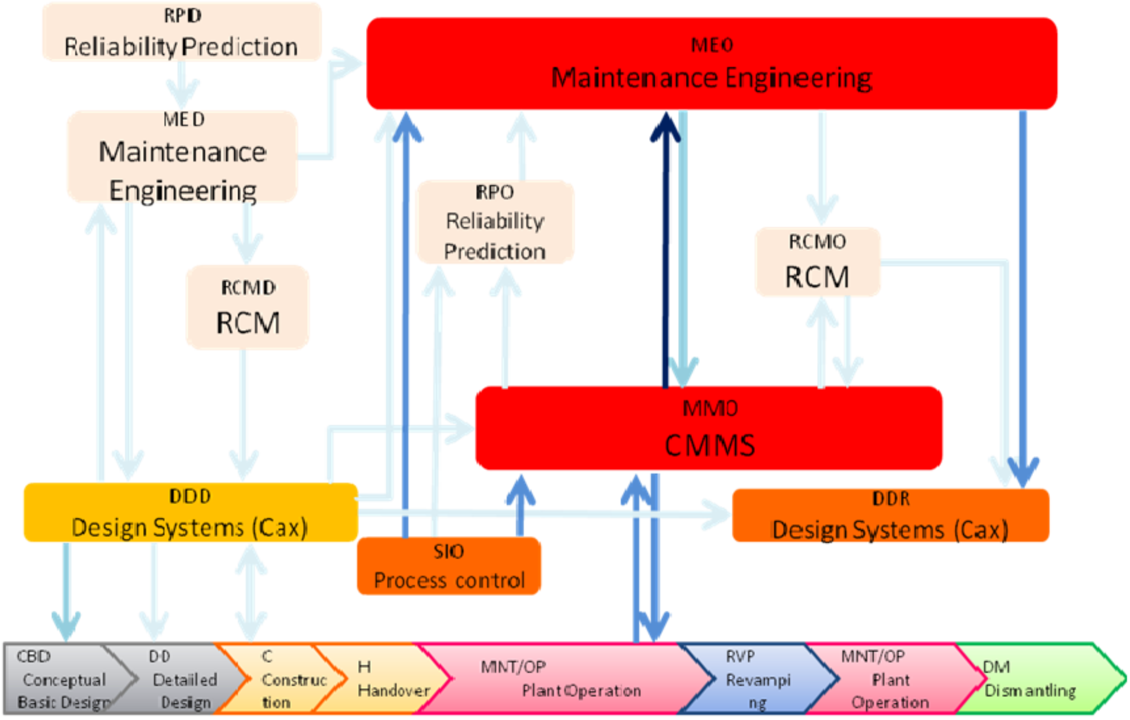


Figure 36: current level of implementation of areas and flows (whole sample)

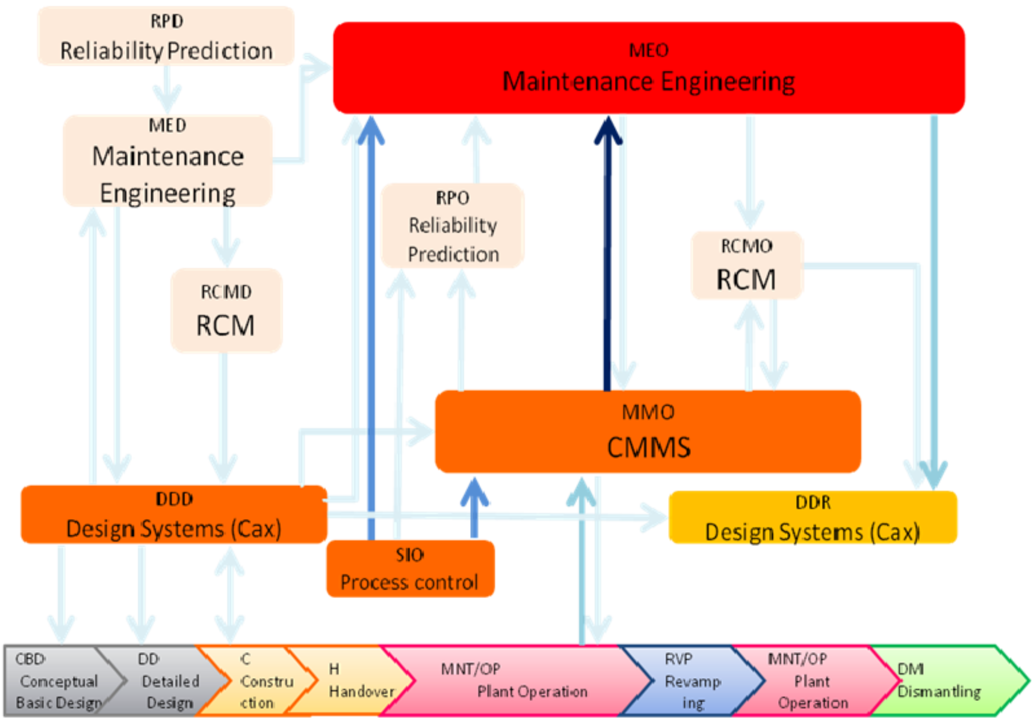


Figure 37: current level of implementation of areas and flows (paper sector)

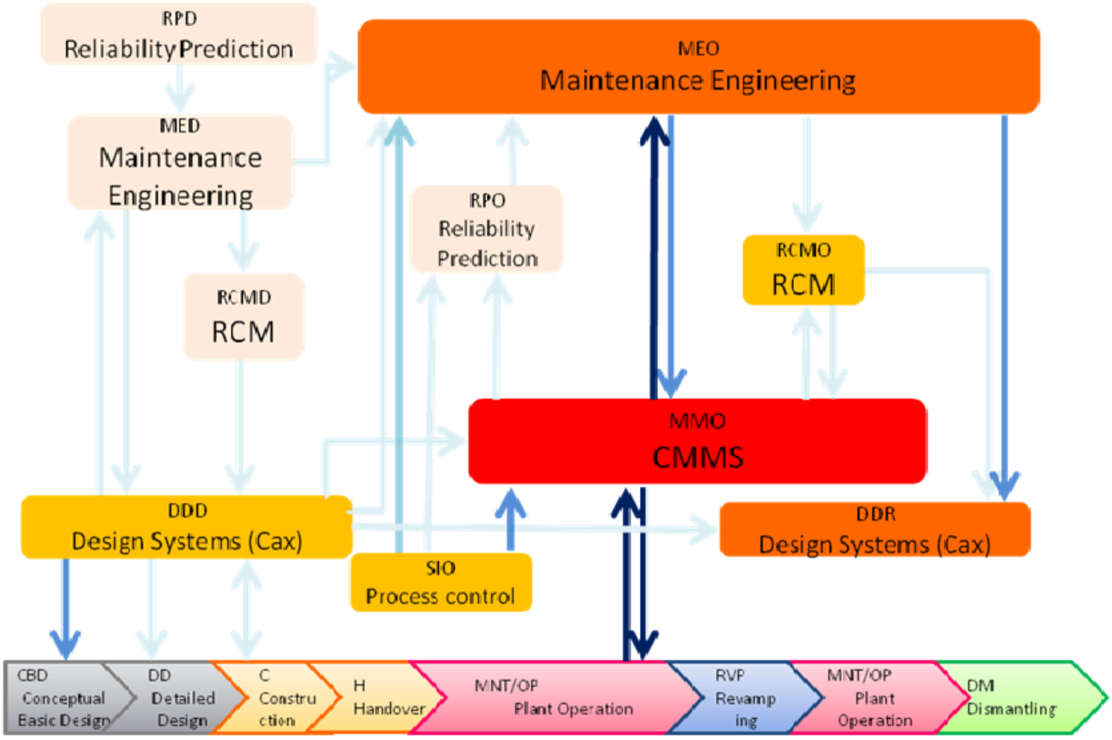


Figure 38: current level of implementation of areas and flows (chemical/pharmaceutical sector)

6.2 Assessment of the current level of automation

In order to verify the current level of automation of the reference model areas, software and information flows, the author has analyzed the answers to the following questions of the questionnaire (see the Chapter 3.3):

- question n°23, for what concerns CMMS and ERP adopted;
- question n°24, for what concerns activities managed by the CMMS;
- question n°29, for what concerns special purpose software currently adopted;
- question n°31, only for what concerns current level of implementation of the information flows of the reference model.

Question n°23 deals with the typology of CMMS adopted, if integrated into the ERP or stand-alone. Results are shown in the picture below:

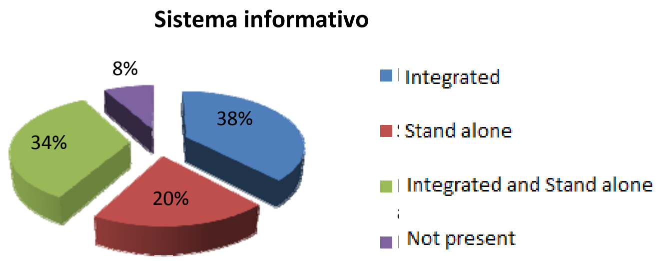


Figure 39: typology of CMMS adopted (whole sample)

The typology of CMMS most implemented is that integrated with the ERP system (38%) and often used in combination with a stand-alone software (34%). Only a small percentage of companies (8%) did not use any type of CMMS. Below the results for the two industrial sectors studied:

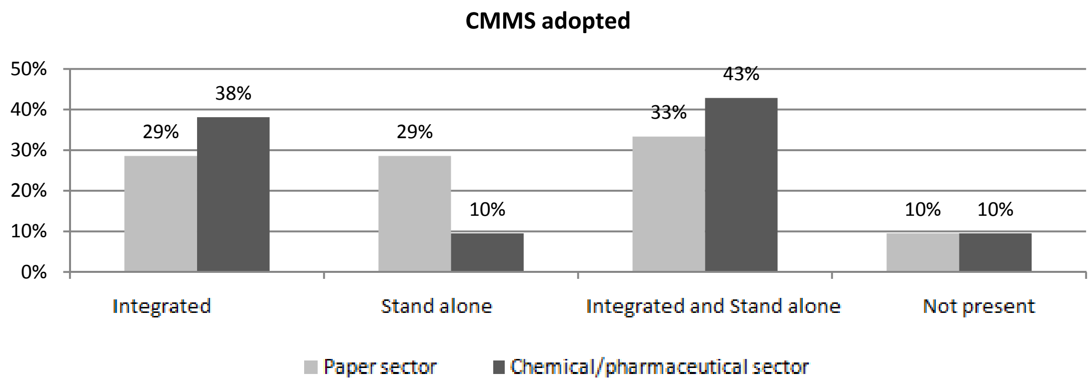


Figure 40: typology of CMMS adopted (paper sector and chemical/pharmaceutical sector)

The 10% of the companies interviewed does not implement any kind of CMMS. In the chemical/pharmaceutical sector integrated solutions are prevalent (or integrated solutions supported by stand alone software), while in the paper sector are prevalent stand alone systems.

The greater level of automation and computerization of chemical/pharmaceutical companies is here well highlighted. Paper companies do not implement an integrated system mainly because of the costs that are considered too high.

Other considerations about the CMMS implementation can be made classifying companies according to their size (in terms of revenue): all the large companies implement a CMMS, often integrated, while small enterprises choose stand alone solutions (it will be verified later that the revenue is an important catalyst for the implementation of these tools in companies).

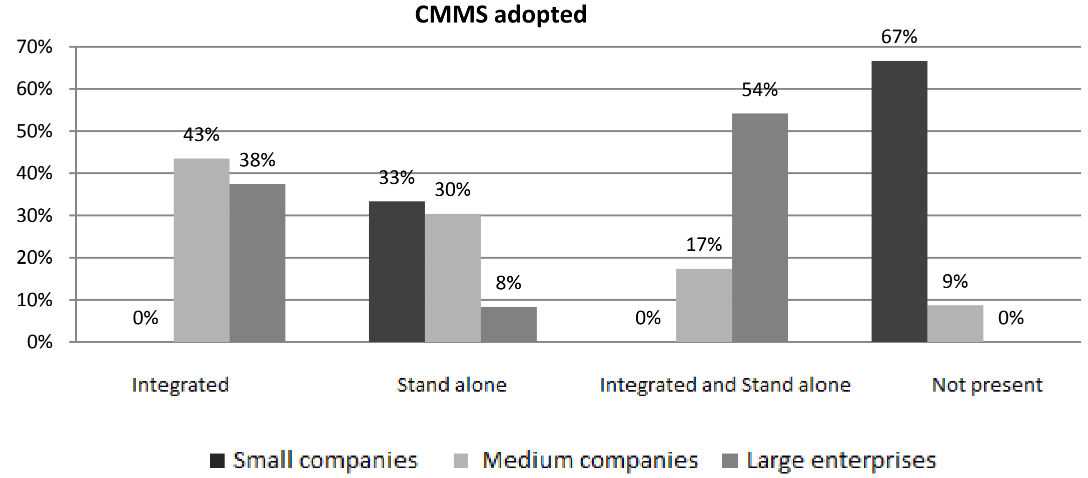


Figure 41: typology of CMMS adopted (whole sample – size classification)

The two pictures below show which are the most implemented software solutions (both integrated and stand alone):

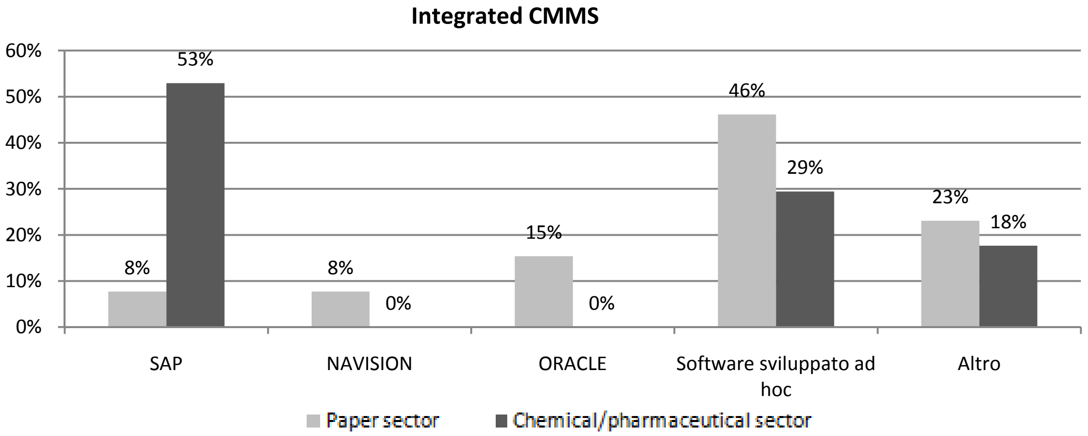


Figure 42: integrated solutions most implemented

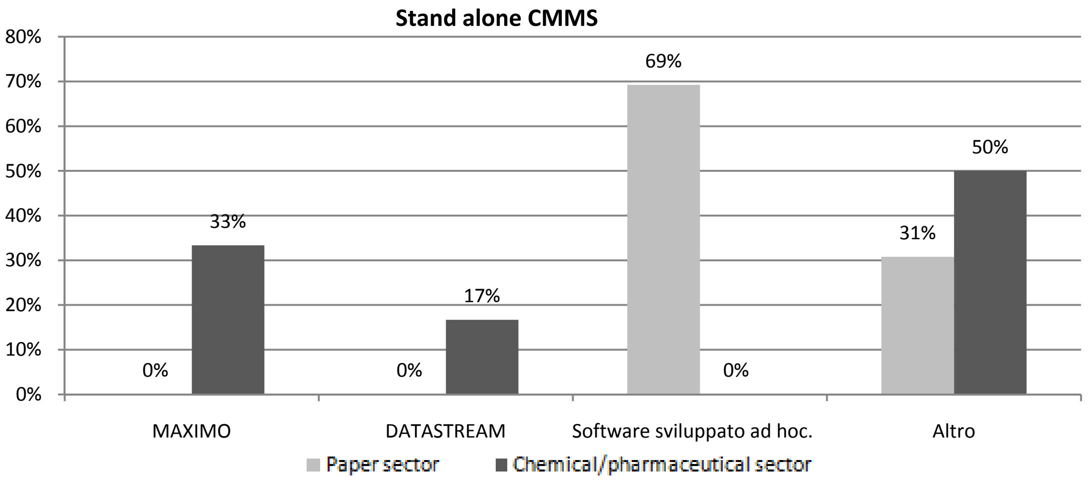


Figure 43: stand alone solutions most implemented

Paper companies show higher levels of adoption of customized solutions internally developed and often very simple (based on MS Access); this probably is due to the lower availability of this sector of resources (in terms of revenue) and of specialized knowledge.
Chemical/pharmaceutical companies, on the other hands, prefer SAP as ERP system and Maximo or Datastream as stand-alone software.
The ERP modules more adopted resulted the following:

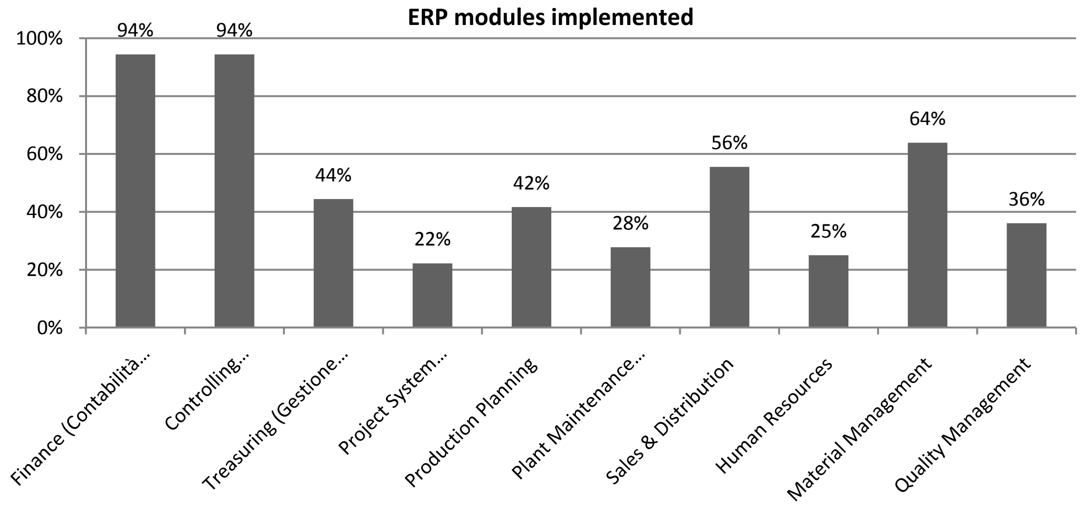


Figure 44: ERP modules implemented (whole sample)

Splitting up the two industrial sectors:

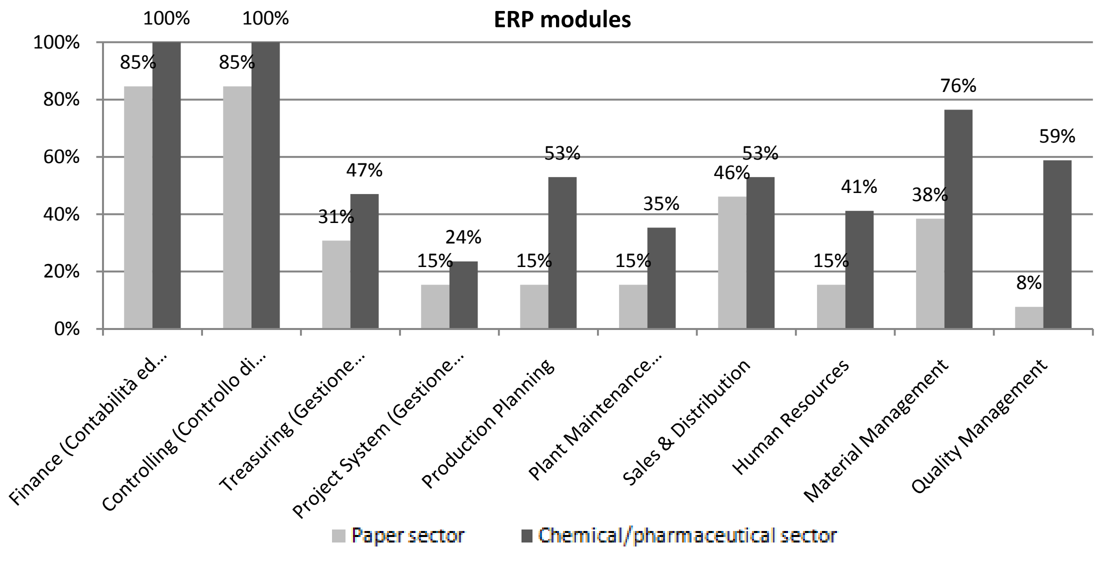


Figure 45: ERP modules implemented (paper sector and chemical/pharmaceutical sector)

For all modules the chemical/pharmaceutical sector presents values of implementation higher than the paper sector; the main differences are found in the human resource, material management, quality management and production planning modules. For the "traditional" activities (as the finance module) this difference is lower.
For a more detailed analysis it is necessary to consider the answers to the question n°24, concerning the activities for which the CMMS is used (in terms of typology and frequency of utilization).
The results of the whole sample are shown below:

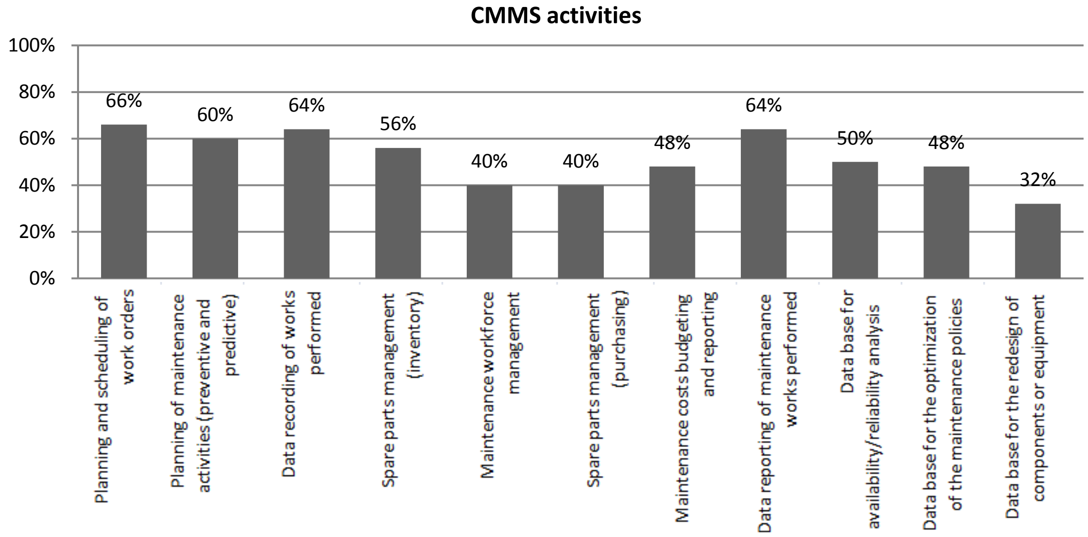


Figure 46: activities for which the CMMS is used (whole sample)

Comparing the activities more implemented with the frequency of use of the CMMS, it results that the more used activities are: planning and scheduling of work orders, planning of maintenance activities (preventive and predictive), data recording of works performed, data reporting of maintenance works performed spare parts inventory and spare parts purchase management.

Analyzing separately the two sectors, it results that the three activities more adopted are:

Table 31: main activities for which the CMMS is implemented (paper sector and chemical/pharmaceutical sector)

	Paper sector	Chemical/pharmaceutical sector
1	Planning of maintenance activities (preventive and predictive)	Planning of maintenance activities (preventive and predictive)
2	Data recording of works performed	Data recording of works performed
3	Data reporting of maintenance works performed	Planning and scheduling of work orders

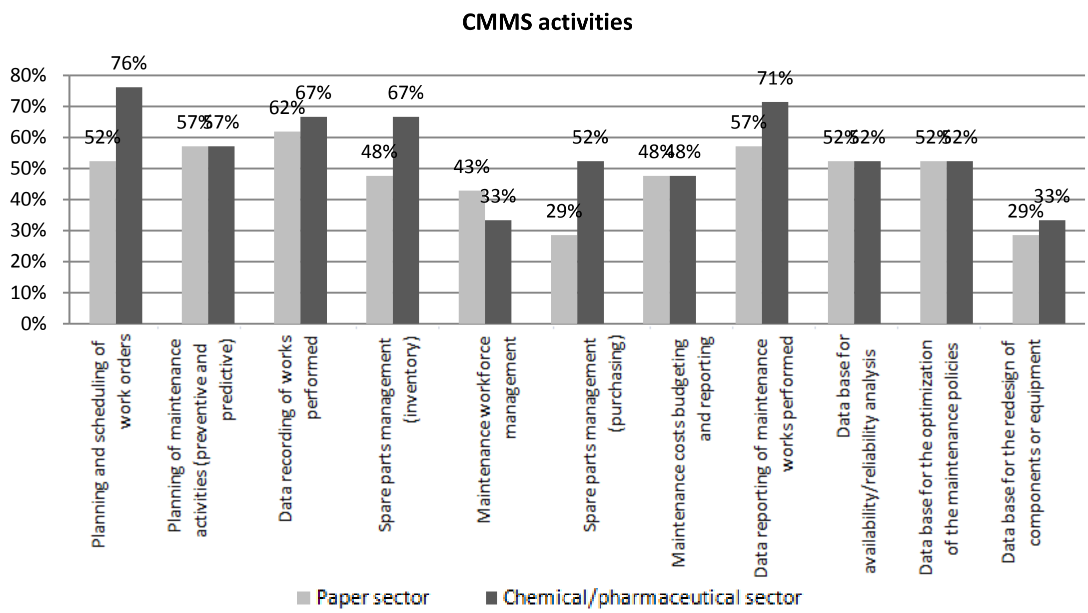


Figure 47: activities for which the CMMS is implemented (paper sector and chemical/pharmaceutical sector)

In the analysis of the activities for which the CMMS is used, it has been found that the company size (in terms of revenues) has a considerable influence. The biggest differences, in fact, has been found between small companies and large-medium enterprises: the first implement the CMMS only for the "planning of maintenance activities (preventive and predictive)" and "data base for the optimization of the maintenance policies ".

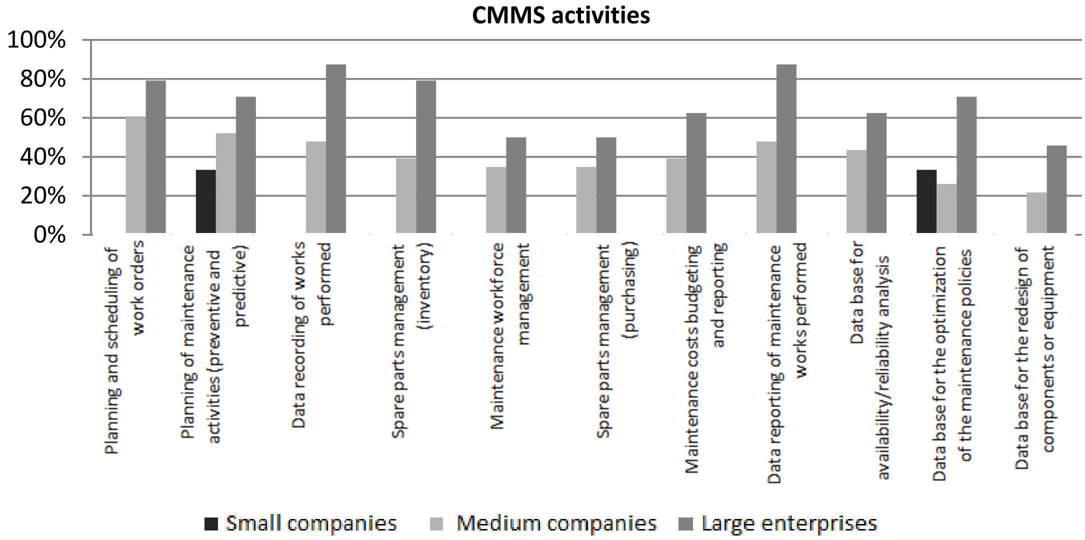
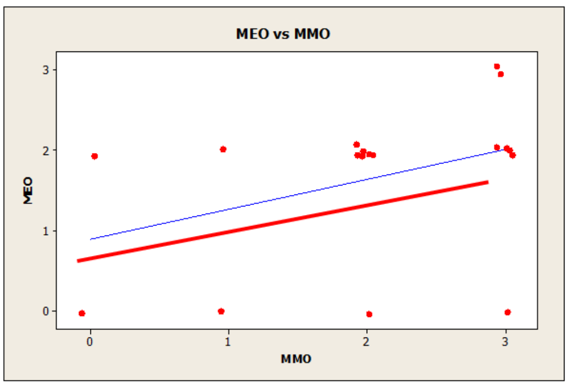


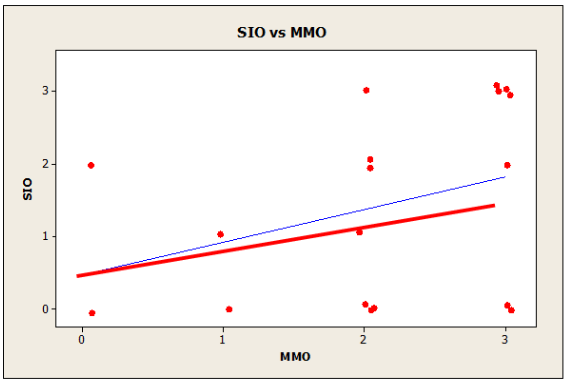
Figure 48: activities for which the CMMS is employed (revenue classification)

Another interesting analysis could be performed assessing if those companies that use "data as source for reliability and availability evaluations", "for the maintenance policies optimization" and "for the redesign of components or equipment", have a strong vertical implementation of the areas.
This analysis assumes that the process that allows data coming from some phases of the maintenance process to be used in other, is facilitated by this vertical integration of areas.
Therefore, below are reported some scatterplots where two lines are shown: the red one is related to the whole sample (is a trend line and indicates the type of correlation between the levels of implementation of the two areas), the blue one is related only to those companies that use the CMMS as a "data source for reliability and availability evaluations", 2for the maintenance policies optimization" and "for the redesign of components or equipment" (the points of the scatterplots are referred to these companies and not to the whole sample).



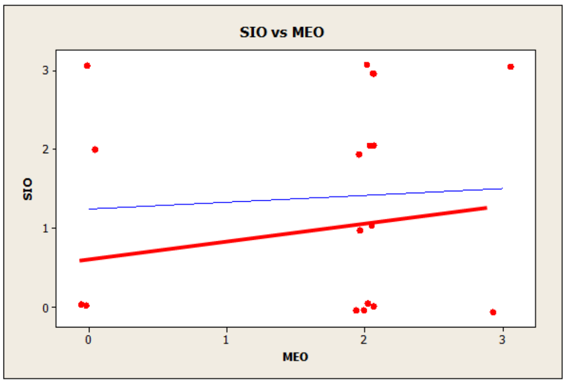
Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 49: Scatterplot of the MEO and MMO areas– trend lines referred to the whole sample (red line) and to those companies that use the CMMS as a data source for reliability and availability evaluations, for the maintenance policies optimization and for the redesign of components or equipment (blue line)



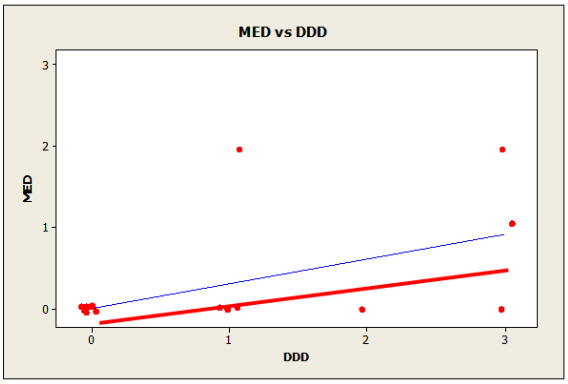
Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 50: Scatterplot of the SIO and MMO areas – trend lines referred to the whole sample (red line) and to those companies that use the CMMS as a data source for reliability and availability evaluations, for the maintenance policies optimization and for the redesign of components or equipment (blue line)



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 51: Scatterplot of the SIO and MEO areas – trend lines referred to the whole sample (red line) and to those companies that use the CMMS as a data source for reliability and availability evaluations, for the maintenance policies optimization and for the redesign of components or equipment (blue line)



Level of implementation	
0	Not present
1	Limited
2	Significant
3	Complete

Figure 52: Scatterplot of the MED and DDD areas – trend lines referred to the whole sample (red line) and to those companies that use the CMMS as a data source for reliability and availability evaluations, for the maintenance policies optimization and for the redesign of components or equipment (blue line)

With the exception of the SIO+MEO scatterplot, the comparison between the blue and red line shows a more significative correlation (greater slope) for companies that use the data as a source for reliability and availability evaluations, for the maintenance policies optimization and for the redesign of components or equipment.

Through the study of the question n°29 it has been possible to analyze the software most used in the following four areas:

- Design/revamping: AutoCad;

- Maintenance Engineering: Maximo, Datastream and CoreMaint;
- Process Control: customized software;
- CMMS: SAP, Maximo and Datastream.

Also considering the two different industrial sectors, the results are the same (in the chemical/pharmaceutical sector, however, there is an higher level of implementation).
To conclude the study of the current level of automation, the answers to the question n°31 (implementation of information flows) concerning the typology of communication adopted for the different information flows, have been analyzed.

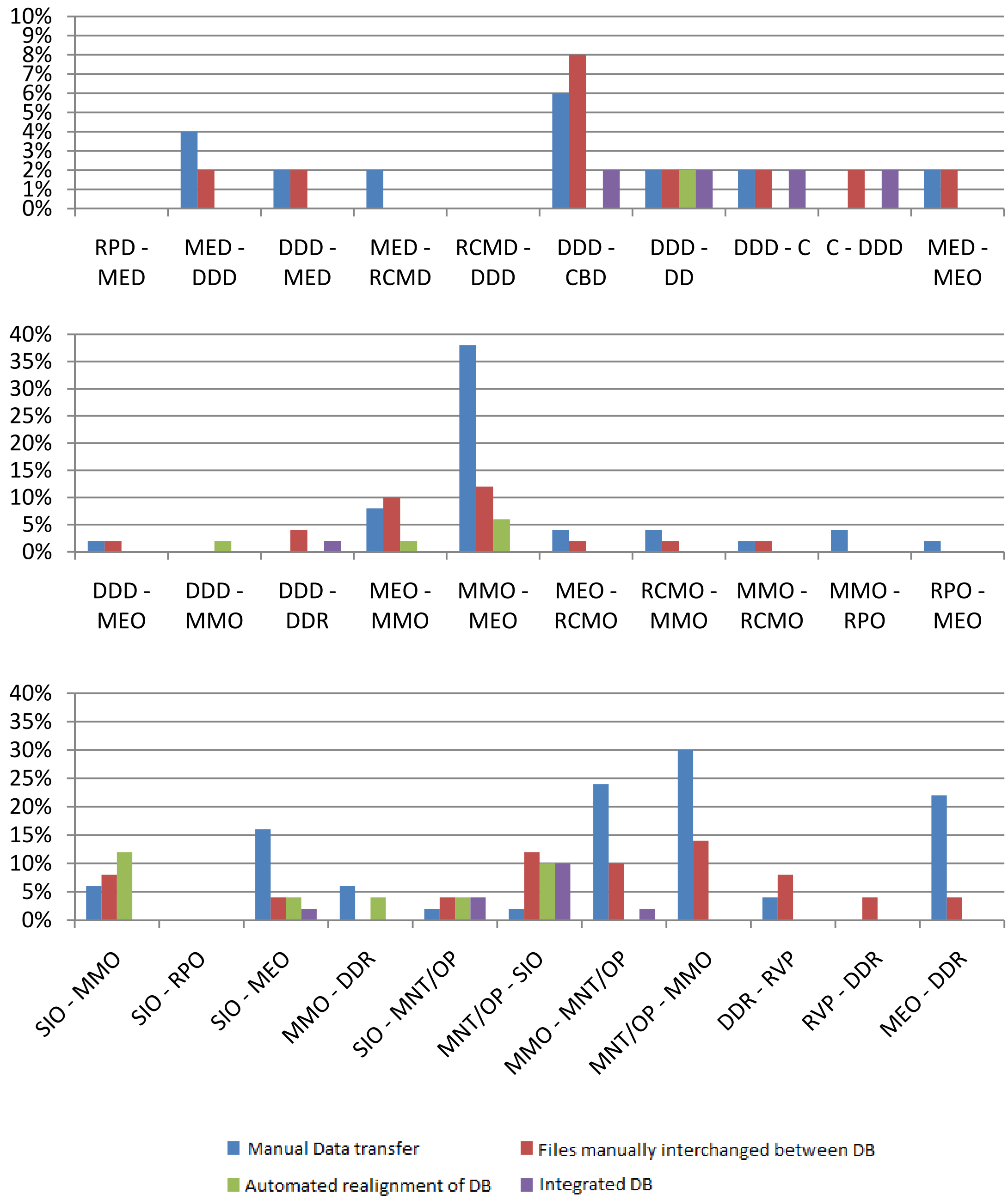


Figure 53: typology of communication of the information flows

The information flows implementation during the design phase is very low. The most interesting flow to study during this phase is the DDD-CBD flow (between the design system area and the conceptual basic design phase).
In the other phases of the plant lifecycle the most interesting flows (from the point of view of the typology of communication) are:

- MMO – MEO;
- MMO- MNT/OP;
- MNT/OP – MMO;
- MEO – DDR ;
- SIO – MEO.

The predominant typology of communication is the data manual transfer, even if a database is available. Only exceptions are the flows that concern the SIO area, but considering that this is the system of supervision and remote control, this result was expected.
Comparing separately the results of the two industrial sectors (analysis limited to the above five principal information flows), it can be seen a predominance of the data manual transfer in the paper sector. In the chemical/pharmaceutical sector, instead, is predominant the data transfer by an “automated realignment of data bases”.
Data transfers carried out by ”integrated databases" are very few in number. This typology of transfer has been found only in the chemical/pharmaceutical sector and only in two paper companies that use very intensively the process control (SIO).
Another important element to consider (still related to question n°31) is the interest showed by companies in an automated information exchange. The results are as follows:

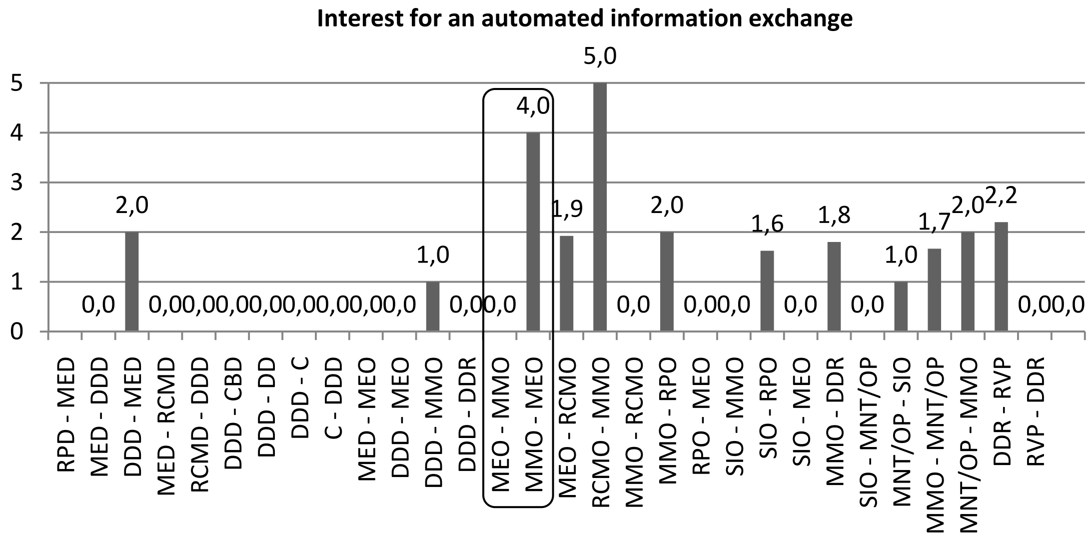


Figure 54: interest showed by companies in an automated information exchange (whole sample)

Some results deserve particular attention: for example, there is an high demand for automation for the flow MMO-MEO but not for the reverse flow MEO-MMO. This situation could be explained by the fact that the CMMS is seen simply as a database from which take information and data. Many companies, especially those of the paper sector, have in fact highlighted how their "maintenance engineering” activity consists in the simple analysis of the fault reports collected into the CMMS and in the subsequent definition of the maintenance policies without using specific tools, but adopting “homemade” methodologies based on the experience. An approach like this requires that the information coming from the MMO area (CMMS) are easily accessible and manageable, but rarely turns into information to resend

to the CMMS in automated mode (often a verbal or written communication about the new maintenance plans is enough). However, it should be noted that, once these information have been recorded into the CMMS, a weak interest for their automated communication to the operational phase (MNT/OP) is observed (for instance by sending reports to the operators palmtops). At a first simple analysis, it could be argued that flows where there is a biggest interest in an automated communication are RCMO-MMO, MMO-MEO and DDR-RVP. This is true, but the level of implementation of the various flows is very different: as seen in the previous sections, the flows more adopted are MMO-MEO, SIO-MMO and SIO-MEO; for the last two interest into a possible automated communication is close to zero: this because systems of the SIO area are adopted mainly to control the production process and not to support the maintenance function.
In conclusion, combining the results concerning the interest for an automated communication of the information flows and the results concerning the flows implementation level, have been identified three flows of particular interest for a more detailed industrial sector analysis: MMO-MEO, MNT/OP-MMO and MNT/OP-SIO:

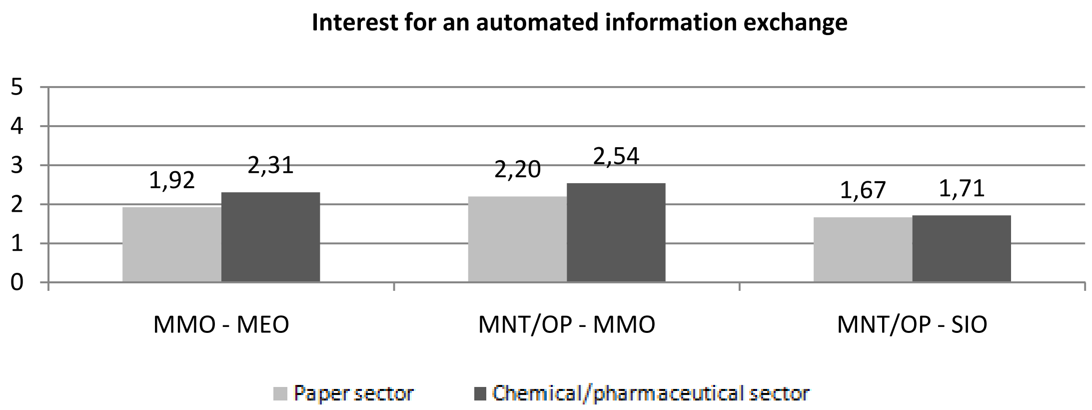


Figure 55: interest showed by companies in an automated information exchange (paper sector and chemical/pharmaceutical sector)

In the chemical/pharmaceutical sector the demand for an automated communication is slightly higher than in the paper industry. Such behavior is probably due to the greater informatization of the chemical/pharmaceutical companies.

6.3 Assessment of the current level of knowledge

To assess the current level of knowledge of the reference model areas, software and information flows, the author has analyzed the answers to the following questions of the questionnaire (see the Chapter 3.3):

- question n°26, only for what concerns the future implementation of the reference model areas and the difference between their importance perceived and their potential importance;
- question n°29, only for what concerns the importance perceived of the special purpose software currently adopted;
- question n°30, only for what concerns the potential importance of the special purpose software planned for a future implementation;
- question n°31, only for what concerns the future implementation of the various information flows and the difference between their importance perceived and their potential importance.

6.3.1 Current level of knowledge of the reference model areas and software

Starting from the analysis of answers to question n°26, the following table shows the number of companies (in percentage) that have planned a future implementation (with a time horizon that can range from 1-2 years, short period, to 5 years, long term) of the different areas of the reference model:

Table 32: future implementation of the reference model areas

	Whole sample	Paper sector	Chemical/pharmaceutical sector
RPD	0,0%	0,0%	0,0%
MED	4,0%	4,8%	4,8%
RCMD	4,0%	0,0%	9,5%
DDD	4,0%	9,5%	0,0%
MEO	34,0%	52,4%	19,0%
RPO	2,0%	0,0%	4,8%
RCMO	6,0%	0,0%	14,3%
SIO	18,0%	28,6%	4,8%
MMO	24,0%	14,3%	33,3%
DDR	8,0%	14,3%	4,8%

The most interesting areas for a future implementation are MEO, SIO, MMO and DDR.
The first three areas are already widely implemented by the companies interviewed, therefore this interest must be intended as a planned future upgrade of the existent area.
In fact, many of these areas (especially the MEO area in the paper sector) present limited levels of implementation and need to be reorganized in order to become more effectiveness.
As regards the DDR area, the paper sector (which has a current level of implementation of this area quite low) shows a low interest for a future implementation, (however, greater than the chemical/pharmaceutical sector where this area is already widely implemented).
For all these four areas, the time horizon for a future implementation is the long-term (more than 5 years); from this point of view, the differences between the two sectors are quite null. Concerning MMO and DDR areas the time horizon is the long term for more than 90% of the companies; concerning the MEO and SIO areas the long term is still prevalent, but with lower percentages. The interest showed by a company for a possible future implementation is an indication of sensibility to these issues (areas, software and information flow). However, the lack of a future implementation does not necessarily indicate a lack of knowledge. In fact it should be performed a crossed analysis with other companies of similar characteristics: if the greater part of these companies implements specific areas and the company examined does not, it should be investigated if this behavior is related to the fact that the company has no need of these areas (but, in this case, it must have alternative solutions to maintain the competitiveness), or cannot afford them, or doesn't know them. This cross-check will be performed in more detail in the analysis of the third sub question.

Question n°26 asks to specify what is the importance perceived of each area implemented and what is the potential importance that this area might have. An interesting element to assess the level of knowledge of the issues treated comes from the analysis of the difference between these two kinds of importance. The following table shows the average values of this difference:

Table 33: average values of the difference between importance perceived and potential importance

	Whole sample	Paper sector	Chemical/pharmaceutical sector
RPD	0,020	0	0,048
MED	0,080	0,048	0,095
RCMD	0,160	0	0,333
DDD	0,040	0,095	0
MEO	0,360	0,238	0,476
RPO	0,180	0	0,286
RCMO	0,200	0	0,333
SIO	0,120	0,286	0
MMO	0,300	0,143	0,381
DDR	0,080	0,095	0,048

Concerning the whole sample, the biggest differences have been observed for the MEO, MMO and RCMO areas (same situation for the chemical/pharmaceutical sector), while for the paper sector the main differences have been observed for the MEO, SIO and MMO areas. The difference between the two importance is an important indicator: in fact, being awareness of the current level of use of an area and awareness that this area could be used in a more rational and complete way is an indication of a deep knowledge of that area.
As mentioned before, to carry out correct considerations, it is necessary to compare companies with similar characteristics in terms of annual revenue:

- Small enterprises (up to € 5 million);
- Medium enterprises (up to € 50 million);
- Large companies (more than € 500 million).

Below are reported the graphs for the MEO, SIO, MMO and DDR areas, which are the most significant and important:

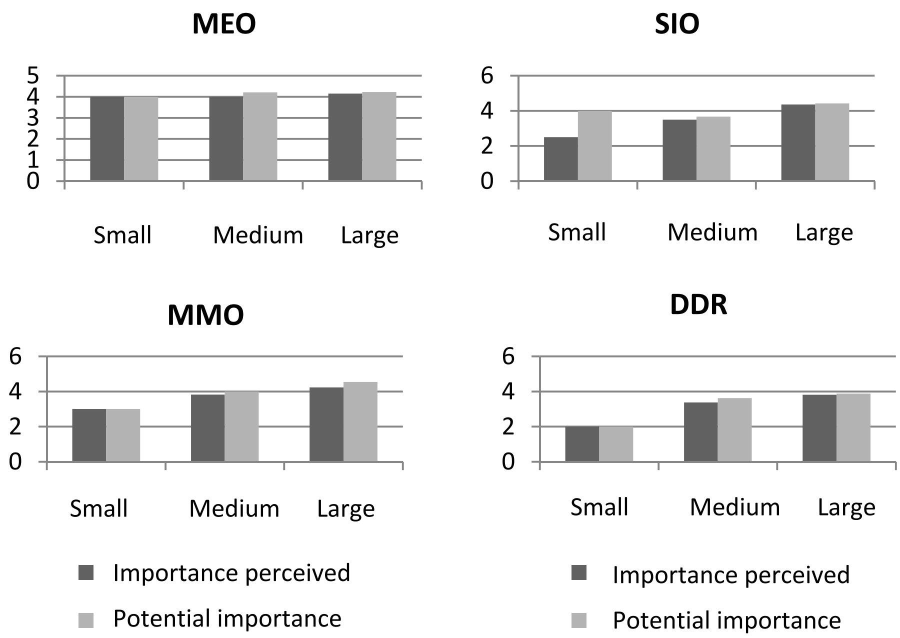


Figure 56: difference between importance perceived and potential importance - areas (revenue classification)

A similar analysis can be performed studying the difference between the potential and perceived importance for what concerns the software currently adopted for each area (question n°29) or planned for a future implementation (question n°30).

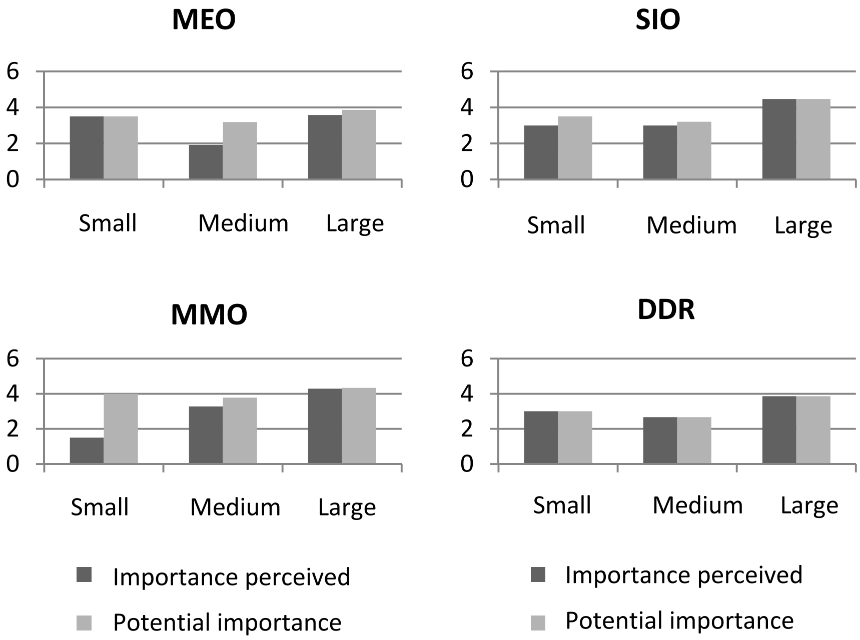


Figure 57: difference between importance perceived and potential importance - software (revenue classification)

For the small companies it is not possible to make general considerations, because their number is very low (only 3 companies contacted).
Therefore, the following conclusions are valid for medium and large enterprises:

- MEO - from the perspective of the area, the level of knowledge is good: the values of importance perceived and potential importance are both quite high (and consequently the gap between them is almost null). From the perspective of software, in large companies there is a good knowledge of the potentialities of the solutions adopted, while in the medium enterprises the awareness of the limited functions of the systems currently adopted (often based on Excel) matches the awareness that with simple changes such tools could become more useful (and this is evidenced by the large gap between the two importance).
- MMO – as the company size increases, also the importance perceived and the potential importance increase both for areas and for software. For the area, can be done the same considerations made for the MEO area. For software, instead, it is observed a moderate level of knowledge by the large and medium companies. However, it should be noted that many medium enterprises implement the CMMS only for managing costs and are aware of the potentiality of this tool (highlighted by the gap between the two importance).
- SIO – also in this case can be done the same considerations made for the MMO area and for its software. In this case, the medium enterprises use data supplied by the SCADA systems only to support and monitor the production. The fact that a discrete potential importance is attributed suggests that these companies be aware of the utility of these information also for maintenance.
- DDR - compared to the previous areas, here is more marked the proportionality between the company size and the level of implementation/knowledge. Concerning

the software, in this case the knowledge is universal, since the software adopted are design programs such as CAD or derivatives;

- OTHER AREAS – for all the other areas not shown in the graphs has been found a strong correlation between the size and the level of adoption/knowledge (many areas such as RPD, MED, RCMD, RCMO and RPO are not implemented by the small and medium enterprises).

Later, other considerations will be made correlating the areas above analyzed with the differences between potential importance and importance perceived of the related information flows.

6.3.2 Current level of knowledge of the information flows

The graph below show the number of companies (as a percentage of the whole sample) that have planned a future implementation of information flows (question n°31).

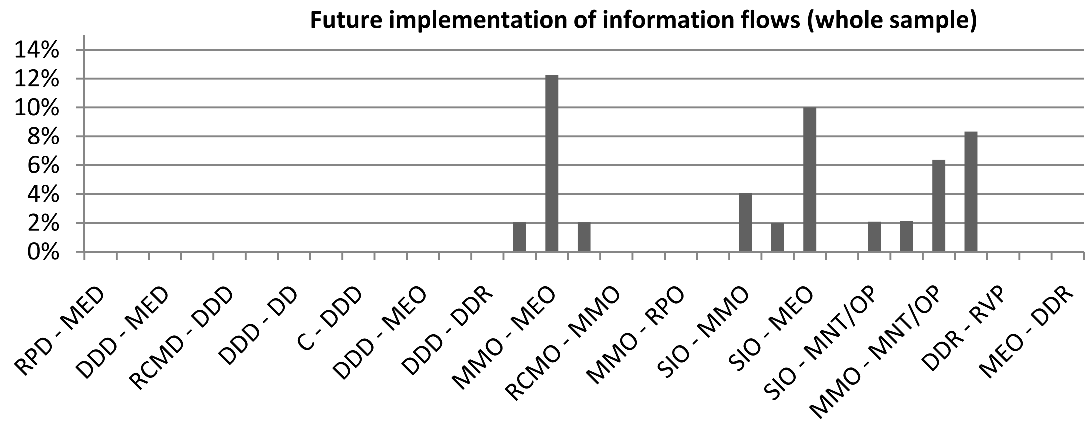


Figure 58: Future implementation of information flows (whole sample)

The most significant flows to analyze are: MMO-MEO, SIO-MEO, MNT/OP-MMO, MMO-MNT/OP e SIO-MMO.

Considering the two industrial sectors (paper and chemical/pharmaceutical sector):

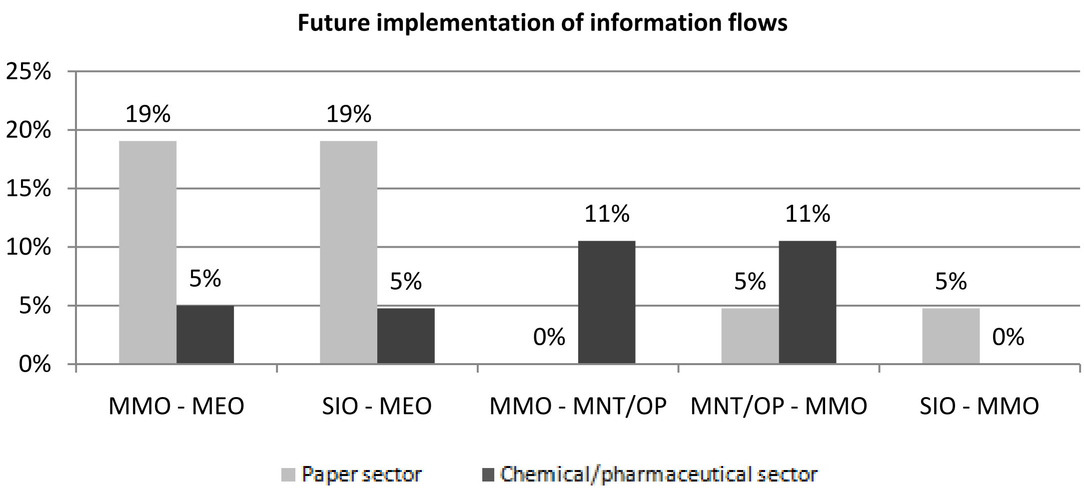


Figure 59: Future implementation of the five most significant information flows (paper sector and chemical/pharmaceutical sector)

The paper sector has plans for a future implementation of flows such as MMO-MEO, SIO-MEO and SIO-MMO in a greater extent than the chemical/pharmaceutical sector. This result can be explained by the fact that, on one hand, this sector has interest to implement in the future the MEO area (see Table 31) and, on the other, implement the SIO area more than the other sector.
The situation is exactly the opposite analyzing the flows MMO-MNT/OP and MNT/OP-MMO. Also this result can be explained through the structural differences between the two industrial sectors: the low presence of the SIO area in the chemical/pharmaceutical sector is offset by a bigger use of the flow MNT/OP-MMO and vice versa (and this is highlighted by the bigger interest for a future implementation).
Both for the chemical/pharmaceutical sector and the paper sector these implementations are mostly planned in the short term (within 2 years). Only the flow SIO-MEO for the paper sector is planned mostly in the medium term (the development of the flow SIO-MMO results to be faster to implement than the SIO-MEO).
From the point of view of the difference between the importance perceived and the potential importance, considerations can be done analyzing this difference in relation to the company size:

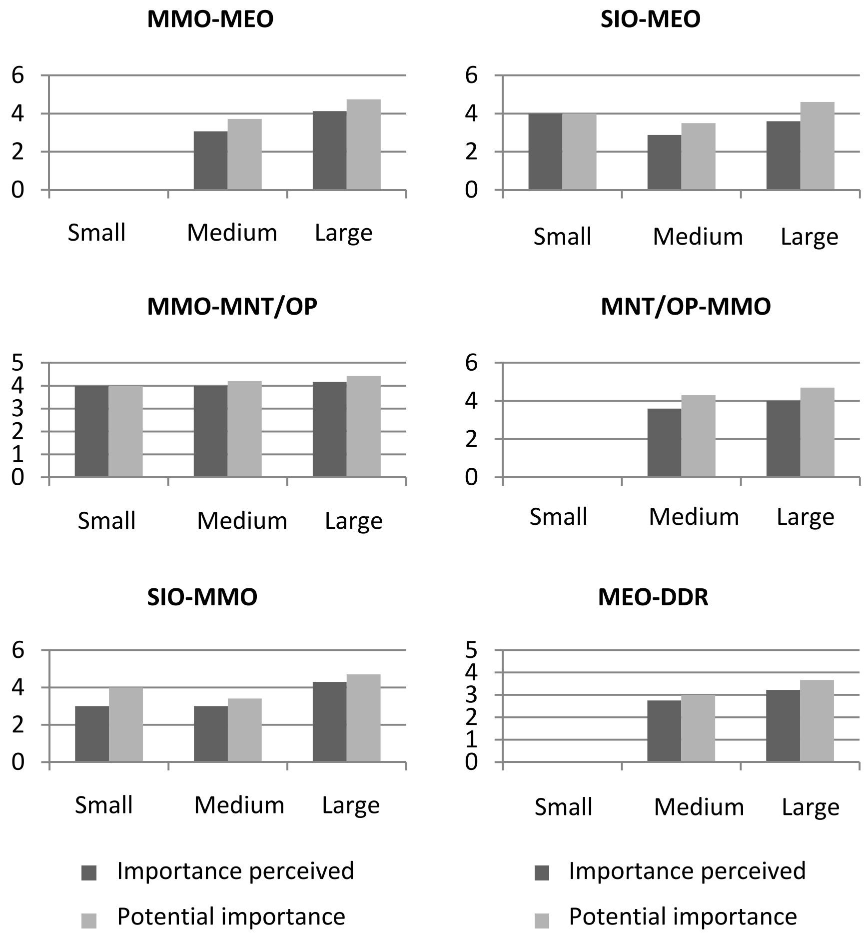


Figure 60: difference between importance perceived and potential importance – information flows (paper sector – chemical/pharmaceutical sector)

In general, excluding the flows that involve the SIO area, for the others it can be observed a strong positive correlation with the company size, especially for those flows that involve the maintenance engineering. Also from the analysis of the other flows emerges that the company size deeply affects the flows adoption and the levels of importance perceived. The

information flows implementation is strongly influenced by the cultural level (on issues of maintenance) of the company, more than the implementation of areas or software.
Another difference between the small-medium enterprises and the large companies is the gap between the potential importance and the importance perceived: such gap is higher in the large companies because is present a stronger corporate culture oriented to maintenance.
Another evidence of these considerations is provided by the following tables where the level of implementation of some areas is compared with the level of implementation of the corresponding information flows (for the small enterprises these tables are omitted).

Table 34: comparison between the presence of the areas and the presence of the corresponding information flow (medium enterprises)

Medium enterprises

AREA	N° of companies	Percentage
MEO	8	35%
MMO	16	70%
SIO	10	43%
MNT/OP	23	100%
DDR	9	39%

FLOW	N° of companies	Percentage	FLOW	N° of companies	Percentage
MEO-MMO	3	13%	MMO-MEO	14	61%
SIO-MNT/OP	2	9%	MNT/OP-SIO	6	26%
SIO-MEO	8	35%	SIO-MMO	5	22%
MMO-MNT/OP	5	22%	MNT/OP-MMO	10	43%
MEO-DDR	4	17%			

Significant considerations can be made analyzing the difference between the levels of adoption of the areas and of the related flows: in the case of medium enterprises this difference is quite high. The flows more implemented are those that involve the MMO and MEO areas, while flows that show the highest discrepancy are those from SIO to MMO and from SIO to the operational phase. In part this is explained by the fact that SCADA systems are often used only to control the production parameters and rarely their information are recorded by the CMMS.

Table 35: comparison between the presence of the areas and the presence of the corresponding information flow (large companies)

Large companies

AREA	N° of companies	Percentage
MEO	16	67%
MMO	21	88%
SIO	13	54%
MNT/OP	24	100%
DDR	12	50%

FLOW	N° of companies	Percentage	FLOW	N° of companies	Percentage
MEO-MMO	10	42%	MMO-MEO	16	67%
SIO-MNT/OP	6	25%	MNT/OP-SIO	10	42%
SIO-MEO	5	21%	SIO-MMO	10	42%
MMO-MNT/OP	12	50%	MNT/OP-MMO	13	54%
MEO-DDR	9	38%			

The simple comparison of the percentages between large and medium enterprises could lead to think that large companies have a greater awareness of the importance of the information exchange between the various areas of the maintenance process. This in part is true, but crossing the level of implementation of the areas with the level of implementation of the related flows, the differences are still considerable (however are lower than those of the medium enterprises: for instance all the companies that implement the maintenance engineering area adopt the MMO-MEO flow. The situation is exactly the opposite of that of the medium companies for the SIO-MEO and SIO-MMO flows. The second appears to be strongly adopted, therefore the data coming from the process control, before reaching the MEO area, transit through the MMO).

Adopting the same approach, it has been performed another cross comparison between:

- the presence of the various areas;
- the presence of the corresponding information flows;
- the presence of a planned future implementation of the flows.

Through this cross check it is possible to analyze for each flow if the information is available (simultaneous presence of two areas), if it is useful (future implementation planned) and if it is used (presence of the flow).

The results are reported in the tables below, separately for industrial sector and company size.

The information is useful, available and used when two areas are adopted, the related flow is present and a future implementation (an upgrade) is planned. The information is available and useful when two areas are present, a future implementation of the related flow is planned, but at the moment the flow is not adopted. The information is available and used when two areas are present, the related flow is implemented but the lack of a future upgrade shows that the flow is not useful for the company or, most likely, the company don't have understood its usefulness (or the flow is implemented at its maximum level, but this condition has never been found in the sample). The information is only available when the two areas are present but not the corresponding flow, and is only useful when a future implementation of a flow is planned but, at the moment, the areas are not present.

Note that the combination "only used" and "useful and used" may not be present individually: both depend on the presence of the areas.

The following figures schematizes these considerations:

- A → information available
- B → information useful
- C → information used *(cannot occur)*
- AB → information available and useful
- AC → information available and used
- BC → information useful and used *(cannot occur)*
- ABC → information available, useful and used

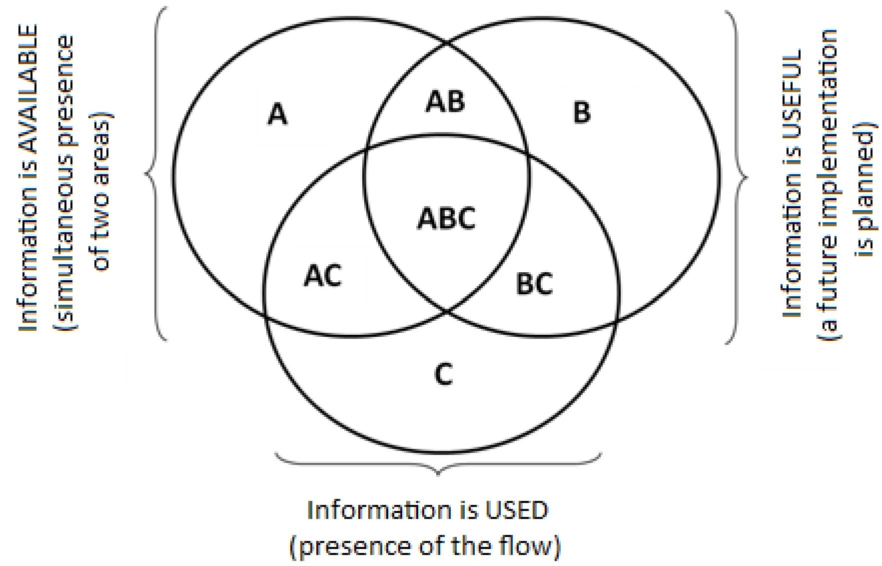


Figure 61: availability, utility and use of the information flow

Table 36: availability, utility and use of the information flow (whole sample)

Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	2%	0%	*98%*
MED - DDD	0%	0%	6%	6%	0%	*88%*
DDD - MED	0%	0%	2%	10%	0%	*88%*
MED - RCMD	0%	0%	2%	0%	0%	*98%*
RCMD - DDD	0%	0%	2%	0%	0%	*98%*
DDD - CBD	0%	0%	16%	24%	0%	*60%*
DDD - DD	0%	0%	8%	32%	0%	*60%*
DDD - C	0%	0%	6%	34%	0%	*60%*
C - DDD	0%	0%	4%	36%	0%	*60%*
MED - MEO	0%	0%	4%	8%	0%	*88%*
DDD - MEO	0%	0%	2%	34%	0%	*64%*
DDD - MMO	0%	0%	2%	28%	0%	*70%*
DDD - DDR	0%	0%	6%	22%	0%	*72%*
MEO - MMO	2%	0%	18%	46%	0%	*34%*
MMO - MEO	10%	0%	44%	12%	2%	*32%*
MEO - RCMO	0%	0%	6%	4%	2%	*86%*
RCMO - MMO	0%	0%	6%	6%	0%	*88%*
MMO - RCMO	0%	0%	2%	10%	0%	*88%*
MMO - RPO	0%	0%	4%	0%	0%	*96%*
RPO - MEO	0%	0%	2%	2%	0%	*96%*
SIO - MMO	2%	2%	22%	20%	0%	*54%*
SIO - RPO	0%	0%	0%	4%	0%	*94%*
SIO - MEO	6%	0%	18%	24%	2%	*48%*
MMO - DDR	0%	0%	10%	42%	0%	*48%*
SIO - MNT/OP	2%	0%	12%	42%	0%	*44%*
MNT/OP - SIO	2%	0%	32%	22%	0%	*2%*
MMO - MNT/OP	4%	0%	32%	46%	2%	*16%*
MNT/OP - MMO	6%	0%	38%	38%	2%	*16%*
DDR - RVP	0%	0%	12%	46%	0%	*42%*
RVP - DDR	0%	0%	4%	54%	0%	*42%*
MEO - DDR	0%	0%	26%	22%	0%	*52%*

Considerations that can be made are:

- The level of implementation of the information flows during the design phase is almost null. It will be seen later if different consideration can be done dividing the sample by sector and size;
- The usefulness of the flow is almost null or at least not understood; the few companies that consider useful a flow are those for which this flow is also available and used;
- Flows that involve the DDD area and some areas of the operational phase (MMO, MEO, SIO and DDR) are those most available, only in some cases they are also used. The flows most implemented are those between the CMMS and the maintenance engineering (MEO), between the CMMS and the operational phase (MNT/OP) and between the operational phase and the activities of process control (SIO).
- Flows in the ABC area are limited to the information exchanged between SIO, MEO and MMO and the percentage of companies that belong to this category is very low.

The following tables describe the results dividing the sample by sector (paper and chemical/pharmaceutical) and size (medium and large enterprise; small companies has been omitted because only three in number):

Table 37: availability, utility and use of the information flow (paper sector)

PAPER SECTOR						
Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	0%	0%	100%
MED - DDD	0%	0%	5%	10%	0%	86%
DDD - MED	0%	0%	0%	14%	0%	86%
MED - RCMD	0%	0%	0%	0%	0%	100%
RCMD - DDD	0%	0%	0%	0%	0%	100%
DDD - CBD	0%	0%	0%	48%	0%	52%
DDD - DD	0%	0%	0%	48%	0%	52%
DDD - C	0%	0%	0%	48%	0%	52%
C - DDD	0%	0%	0%	48%	0%	52%
MED - MEO	0%	0%	0%	14%	0%	86%
DDD - MEO	0%	0%	0%	48%	0%	52%
DDD - MMO	0%	0%	0%	29%	0%	71%
DDD - DDR	0%	0%	0%	24%	0%	76%
MEO - MMO	5%	0%	0%	62%	0%	33%
MMO - MEO	14%	0%	38%	14%	5%	29%
MEO - RCMO	0%	0%	0%	0%	5%	95%
RCMO - MMO	0%	0%	0%	0%	0%	100%
MMO - RCMO	0%	0%	0%	0%	0%	100%
MMO - RPO	0%	0%	0%	0%	0%	100%
RPO - MEO	0%	0%	0%	5%	0%	95%
SIO - MMO	5%	0%	29%	19%	0%	48%
SIO - RPO	0%	0%	0%	5%	0%	95%
SIO - MEO	14%	0%	29%	29%	0%	29%
MMO - DDR	0%	0%	0%	38%	0%	62%
SIO - MNT/OP	0%	0%	10%	62%	0%	29%
MNT/OP - SIO	0%	0%	29%	43%	0%	29%
MMO - MNT/OP	0%	0%	10%	62%	0%	29%
MNT/OP - MMO	5%	0%	19%	48%	0%	29%
DDR - RVP	0%	0%	0%	43%	0%	57%
RVP - DDR	0%	0%	0%	43%	0%	57%
MEO - DDR	0%	0%	19%	24%	0%	57%

Table 38: availability, utility and use of the information flow (chemical/pharmaceutical sector)

CHEMICAL/PHARMACEUTICAL SECTOR						
Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	0%	0%	100%
MED - DDD	0%	0%	5%	5%	0%	90%
DDD - MED	0%	0%	0%	10%	0%	90%
MED - RCMD	0%	0%	5%	0%	0%	95%
RCMD - DDD	0%	0%	5%	0%	0%	95%
DDD - CBD	0%	0%	29%	10%	0%	62%
DDD - DD	0%	0%	10%	29%	0%	62%
DDD - C	0%	0%	5%	33%	0%	62%
C - DDD	0%	0%	5%	33%	0%	62%
MED - MEO	0%	0%	5%	5%	0%	90%
DDD - MEO	0%	0%	0%	29%	0%	71%
DDD - MMO	0%	0%	5%	29%	0%	67%
DDD - DDR	0%	0%	10%	24%	0%	67%
MEO - MMO	0%	0%	38%	29%	0%	33%
MMO - MEO	5%	0%	57%	5%	0%	33%
MEO - RCMO	0%	0%	14%	5%	0%	81%
RCMO - MMO	0%	0%	14%	5%	0%	81%
MMO - RCMO	0%	0%	5%	14%	0%	81%
MMO - RPO	0%	0%	5%	0%	0%	95%
RPO - MEO	0%	0%	5%	0%	0%	95%
SIO - MMO	0%	0%	24%	14%	0%	62%
SIO - RPO	0%	0%	0%	0%	0%	100%
SIO - MEO	0%	0%	10%	19%	5%	67%
MMO - DDR	0%	0%	14%	52%	0%	33%
SIO - MNT/OP	0%	0%	10%	29%	0%	62%
MNT/OP - SIO	0%	0%	38%	0%	0%	62%
MMO - MNT/OP	5%	0%	48%	38%	5%	5%
MNT/OP - MMO	5%	0%	52%	33%	5%	5%
DDR - RVP	0%	0%	14%	62%	0%	24%
RVP - DDR	0%	0%	5%	71%	0%	24%
MEO - DDR	0%	0%	43%	0%	10%	48%

Table 39: availability, utility and use of the information flow (medium enterprises)

MEDIUM ENTERPRISES						
Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	0%	0%	100%
MED - DDD	0%	0%	5%	0%	0%	95%
DDD - MED	0%	0%	0%	5%	0%	95%
MED - RCMD	0%	0%	0%	0%	0%	100%
RCMD - DDD	0%	0%	0%	0%	0%	100%
DDD - CBD	0%	0%	9%	27%	0%	64%
DDD - DD	0%	0%	5%	32%	0%	64%
DDD - C	0%	0%	5%	32%	0%	64%
C - DDD	0%	0%	0%	36%	0%	64%
MED - MEO	0%	0%	0%	5%	0%	95%
DDD - MEO	0%	0%	0%	36%	0%	64%
DDD - MMO	0%	0%	0%	27%	0%	73%
DDD - DDR	0%	0%	0%	23%	0%	77%
MEO - MMO	0%	0%	5%	64%	0%	32%
MMO - MEO	9%	0%	45%	14%	5%	27%

MEO - RCMO	0%	0%	0%	0%	5%	95%
RCMO - MMO	0%	0%	0%	0%	0%	100%
MMO - RCMO	0%	0%	0%	0%	0%	100%
MMO - RPO	0%	0%	0%	0%	0%	100%
RPO - MEO	0%	0%	0%	0%	0%	100%
SIO - MMO	0%	5%	18%	18%	0%	59%
SIO - RPO	0%	0%	0%	0%	0%	100%
SIO - MEO	9%	0%	23%	23%	0%	45%
MMO - DDR	0%	0%	9%	36%	0%	55%
SIO - MNT/OP	0%	0%	5%	50%	0%	45%
MNT/OP - SIO	0%	0%	27%	27%	0%	45%
MMO - MNT/OP	0%	0%	27%	55%	0%	18%
MNT/OP - MMO	5%	0%	41%	36%	0%	18%
DDR - RVP	0%	0%	9%	41%	0%	50%
RVP - DDR	0%	0%	0%	50%	0%	50%
MEO - DDR	0%	0%	18%	27%	0%	55%

Table 40: availability, utility and use of the information flow (large companies)

LARGE ENTERPRISES						
Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	4%	0%	96%
MED - DDD	0%	0%	8%	13%	0%	79%
DDD - MED	0%	0%	4%	17%	0%	79%
MED - RCMD	0%	0%	4%	0%	0%	96%
RCMD - DDD	0%	0%	4%	0%	0%	96%
DDD - CBD	0%	0%	25%	21%	0%	54%
DDD - DD	0%	0%	13%	33%	0%	54%
DDD - C	0%	0%	8%	38%	0%	54%
C - DDD	0%	0%	8%	38%	0%	54%
MED - MEO	0%	0%	8%	13%	0%	79%
DDD - MEO	0%	0%	4%	33%	0%	63%
DDD - MMO	0%	0%	4%	33%	0%	63%
DDD - DDR	0%	0%	13%	25%	0%	63%
MEO - MMO	4%	0%	33%	33%	0%	29%
MMO - MEO	13%	0%	50%	8%	0%	29%
MEO - RCMO	0%	0%	13%	8%	0%	79%
RCMO - MMO	0%	0%	13%	13%	0%	75%
MMO - RCMO	0%	0%	4%	21%	0%	75%
MMO - RPO	0%	0%	8%	0%	0%	92%
RPO - MEO	0%	0%	4%	4%	0%	92%
SIO - MMO	4%	0%	25%	25%	0%	46%
SIO - RPO	0%	0%	0%	8%	0%	92%
SIO - MEO	0%	0%	13%	29%	4%	54%
MMO - DDR	0%	0%	8%	54%	0%	38%
SIO - MNT/OP	4%	0%	21%	33%	0%	42%
MNT/OP - SIO	4%	0%	38%	17%	0%	42%
MMO - MNT/OP	8%	0%	38%	42%	4%	8%
MNT/OP - MMO	8%	0%	42%	38%	4%	8%
DDR - RVP	0%	0%	17%	54%	0%	29%
RVP - DDR	0%	0%	8%	63%	0%	29%
MEO - DDR	0%	0%	38%	21%	0%	42%

The comparison between the two industrial sectors generates conflicting results: the paper sector presents better results for the category of flows available, useful and used (and in

some cases also for the category "available") but the level of implementation is generally lower than the level of the chemical/pharmaceutical sector. Concerning the category “useful”, the percentages are low; companies consider a flow useful, because it has already been adopted or is available.
In the comparison based on the size is more relevant the difference between medium and large companies: the latter have higher levels of implementation and availability of the flows and have also higher percentages for the category ABC.
In conclusion, the more relevant factors that influence the knowledge are related to the company size, and only in part to the industrial sector.
To confirm this conclusion, the percentage of the various categories (A, B, AB, AC and ABC) for the large companies of the chemical/pharmaceutical sector has been calculated. What has been achieved (especially for the category "available" and "available and used”) supports the considerations just made (values on average higher than those in the previous tables).

Table 41: availability, utility and use of the information flow (large chemical/pharmaceutical enterprises)

LARGE CHEMICAL/PHARMACEUTICAL ENTERPRISES						
Information Flow	**Available, useful and used**	**Available and useful**	**Available and used**	**Available**	**Useful**	***Companies lacking the 3 parameters***
RPD - MED	0%	0%	0%	0%	0%	100%
MED - DDD	0%	0%	7%	7%	0%	87%
DDD - MED	0%	0%	0%	13%	0%	87%
MED - RCMD	0%	0%	7%	0%	0%	93%
RCMD - DDD	0%	0%	7%	0%	0%	93%
DDD - CBD	0%	0%	33%	7%	0%	60%
DDD - DD	0%	0%	13%	27%	0%	60%
DDD - C	0%	0%	7%	33%	0%	60%
C - DDD	0%	0%	7%	33%	0%	60%
MED - MEO	0%	0%	7%	7%	0%	87%
DDD - MEO	0%	0%	0%	27%	0%	73%
DDD - MMO	0%	0%	7%	27%	0%	67%
DDD - DDR	0%	0%	13%	27%	0%	60%
MEO - MMO	0%	0%	53%	20%	0%	27%
MMO - MEO	7%	0%	67%	0%	0%	27%
MEO - RCMO	0%	0%	20%	7%	0%	73%
RCMO - MMO	0%	0%	20%	7%	0%	73%
MMO - RCMO	0%	0%	7%	20%	0%	73%
MMO - RPO	0%	0%	7%	0%	0%	93%
RPO - MEO	0%	0%	7%	0%	0%	93%
SIO - MMO	0%	0%	33%	13%	0%	53%
SIO - RPO	0%	0%	0%	0%	0%	100%
SIO - MEO	0%	0%	13%	20%	7%	60%
MMO - DDR	0%	0%	7%	67%	0%	27%
SIO – MNT/OP	0%	0%	13%	33%	0%	53%
MNT/OP - SIO	0%	0%	47%	0%	0%	53%
MMO - MNT/OP	7%	0%	53%	27%	7%	7%
MNT/OP - MMO	7%	0%	47%	33%	7%	7%
DDR - RVP	0%	0%	20%	67%	0%	13%
RVP - DDR	0%	0%	7%	80%	0%	13%
MEO - DDR	0%	0%	53%	13%	0%	33%

6.4 *Conclusions of the chapter*

This chapter focuses on the assessment of the level of implementation, automation and knowledge of the reference model areas, software and information flows.

Concerning the level of implementation, areas most adopted are those of the operational phase (also because many companies do not deal with the design phase), such as SIO, MMO and MEO. The level of implementation is influenced by the industrial sector (the SIO area prevails in the paper industry, the MMO area in the chemical/pharmaceutical sector) and by the size of the company (in terms of revenue and availability of qualified personnel).

Concerning the level of automation, also the informatization is strongly influenced by the size of the companies studied, while the industrial sector influence some parts of the maintenance process rather than others. Areas more automated are resulted the SIO and the MMO (CMMS). In terms of software adopted, the paper companies, both for lower needs of informatization and for less resources available often implement very simple software, homemade, based on MS Access. In the chemical/pharmaceutical companies, instead, are heavily used software such as SAP, Maximo and Datastream.

Finally in terms of knowledge, also here the results are influenced by the size of the companies and by the industrial sector (especially by the size for the information flows), however, in this case is relevant the mentality of the company and the competences of people who deal with maintenance.

7. *Assessment of the survey validity*

As described in the Chapter 4, the internal validity of this work has been verified comparing the results obtained with the results of other similar works (the so called Criterion Related Validity). This comparison has been also used to give an external validity to this work, allowing to generalize the results and to extend them to all the population represented by the sample.
In this chapter will be treated this process of comparison with other similar survey found in the scientific literature.
These comparable surveys have been chosen considering:

- when they have been submitted (the data collection year can affect the results);
- what kind of population they have considered (for example, if a comparable survey is focused on the chemical industry, it should be compared not with the results of the whole sample of this work, but only with those of the chemical/pharmaceutical sector).

The oldest survey found for this comparison dates back to 1997, while the others to 1999, 2004 and 2007. The year of data collection does not have influenced the results: in fact, comparing the results of the oldest survey with those of this work, many point in common have been found.
Unfortunately it was not always possible to obtain precise information about the population, therefore the comparison will be performed principally with the results obtained from the whole sample.

SURVEY A: the first survey considered for this comparison has been conducted by the "Plant Maintenance Resource Center" in the 2004 and involves 105 companies based in USA, Australia, Canada and UK (mainly belonging to the oil and gas, food, metal production and electricity production sectors). The aim of this survey has been to understand how many companies implement the CMMS, which are the most used CMMS and why they are the most preferred.

Table 42: comparison of CMMS implementation - survey A

	Survey A	This work
Sample interviewed	105	50
Companies that implement a CMMS (as a percentage of the whole sample)	81.9%	82,0%

The most implemented CMMS are (in order) SAP, Maximo and MP2, while in this work are SAP, Maximo and Datastream. Being MP2 a product Datastream, it can be asserted that the results are practically coincident as regards both the level of adoption and the type of software implemented.

SURVEY B: another survey used for the comparison has been conducted in the 2007, again by the "Plant Maintenance Resource Center", and concerns the implementation of RCM approaches in companies [61].
The results provided by the "Plant Maintenance Resource Center" show that the 64% of companies interviewed adopt this approach. In this work, aggregating the results of RCMD and RCMO, the percentage obtained is the 16%. Limiting this analysis to the chemical/pharmaceutical sector, this percentage rises to 24%.

This result was expected: in fact this discipline is still not widely implemented in Italy.

SURVEY C: Also the following survey has been conducted by the "Plant Maintenance Resource Center" in the 1999 on a sample of 20 Anglo-Saxon companies [62]. In this case the comparison has been performed on the adoption of techniques such as the DFR (Design for Reliability). The level of adoption found in this work is significantly different from that of the survey C (this difference is lower for companies of the chemical/pharmaceutical sector).

Table 43: comparison of DFR techniques adoptions - survey C

	This work					
	Whole sample		**Paper sector**		**Chemical/pharmaceutical sector**	
	N° of companies	%	N° of companies	%	N° of companies	%
DFR implemented	13	26%	4	19%	8	38%
Not implemented	37	74%	17	81%	13	62%

	Survey C	
	N° of companies	%
DFR implemented	31	62%
Not implemented	19	38%

Eliminating from the sample all the companies that do not implement the design phase, this difference is reduced (almost null for the chemical/pharmaceutical sector):

Table 44: comparison of DFR techniques adoptions in companies that perform the design of their own plants - survey C

	This work			**Survey C**
	Whole sample	**Paper sector**	**Chemical/pharmaceutical sector**	
DFR implemented	48%	36%	67%	62%
Not implemented	52%	64%	33%	38%

To verify these results has been performed a chi-square test on the difference between the frequencies (percentages), adopting a significance level of 5% and the null hypothesis H_0 = "*the observed frequencies (results of this work) do not differ from those expected (results of the Survey C)*":

Table 45: Chi-square test on the difference between the results of this work and those of the Survey C

	Whole sample	**Paper sector**	**Chemical/pharmaceutical sector**
Chi-square test	0,083191851	0,24824278	0,010611
Critical value	0,004		

Because all the value obtained are bigger than the critical value, the null hypothesis is rejected, therefore the two results differ from each other. Bigger is χ^2 and bigger is this discrepancy.

SURVEY D: this survey has been conducted by Imad Alsyouf in the 2007 on a sample of 118 Swedish companies [63]. The aim of this survey has been the assessment of the maintenance practices commonly used in the Swedish industry. The sample contains companies of different sectors: oil and gas, food, metal production and electricity production. To compare this work with the survey D, the questions n°20 and n°21 (which deal with the maintenance organization) have been considered: the first asks if the maintenance function is a business function, while the second asks if maintenance is centralized, decentralized or mixed type.

Results for question 20 are:

Table 46: comparison of maintenance organization – Survey D

	This work			Survey D
	Whole sample	**Paper sector**	**Chemical/pharmaceutical sector**	
Maintenance is a business function	82%	71%	95%	42%
Maintenance isn't a business function	18%	29%	5%	56%

Results obtained are different: there is a substantial equality in the results of the Swedish sample, whereas in the Italian companies there is an high prevalence of the maintenance as independent business function.

The chi-square test shows very high values (significance level of 5% and H_0 = "*the observed frequencies do not differ from those expected*"), therefore the null hypothesis is rejected.

Table 47: Chi-square test on the difference between the results of this work and those of the Survey D

	Whole sample	**Paper sector**	**Chemical/pharmaceutical sector**
Chi-square test	0,63880952	0,33041667	1,13332274
Critical value	0,004		

Results of question 21 are:

Table 48: comparison of the level of decentralization of maintenance - Survey D

	This work			Survey D
	Whole sample	**Paper sector**	**Chemical/pharmaceutical sector**	
Centralized	34%	**38%**	29%	**41%**
Mixed	10%	5%	14%	41%
Decentralized	56%	57%	57%	18%

The frequencies of adoption of a centralized maintenance system are quite similar if compared to the paper sector. The adoption of mixed and decentralized maintenance systems follows an opposite trend. In this work there is a strong adoption of decentralized systems rather than mixed system, in the survey D the result is exactly the opposite. The results of the chi-square test are:

Table 49: Chi-square test on the difference between the results of this work and those of the Survey D

	Whole sample	Paper sector	Chemical/pharmaceutical sector
Chi-square test	1,04856368	1,163292683	1,057926829
Critical value	0,103		

The null hypothesis is rejected, therefore a significative difference is observed.

SURVEY E: the last survey used for the validation is the work of Laura Swanson "An empirical study of the Relationship Between production technology and maintenance management", published in 1997 [33].
Swanson investigates on the relationship between the production technology and the maintenance policies adopted. To perform a comparison, the result of the questions n°14, 15, 16 and 17 have been crossed with those of the questions 21, 21 bis and 26:

Table 50: level of decentralization of maintenance crossed with the technical complexity – comparison with Survey E

	This work		Survey E	
	High complex-ity	**Low complex-ity**	**High com-plexity**	**Low complexi-ty**
Centralized	35%	40%	40%	53%
Decentralized	65%	60%	60%	47%

Table 51: level of decentralization of maintenance crossed with the technical complexity – comparison with Survey E – Chi-square test

	High com-plexity	Low complex-ity
Chi-square test	0,010416667	0,067844239
Critical value	0,004	

Table 52: level of decentralization of maintenance crossed with the interdependence – comparison with Survey E

	This work		Survey E	
	High interde-pendence	**Low interde-pendence**	**High interde-pendence**	**Low interde-pendence**
Centralized	**36%**	39%	**38%**	53%
Decentralized	**64%**	61%	**62%**	47%

Table 53: level of decentralization of maintenance crossed with the interdependence – comparison with Survey E – Chi-square test

	High interde-pendence	Low interde-pendence
Chi-square test	**0,001697793**	0,07868326
Critical value	0,004	

Table 54: presence of a CMMS crossed with the technical complexity - comparison with Survey E

	This work		Survey E	
	High complexity	**Low complexity**	**High complexity**	**Low complexity**
CMMS present	22%	15%	37%	31%
CMMS not adopted	78%	85%	63%	69%

Table 55: presence of a CMMS crossed with the technical complexity – comparison with Survey E – Chi-square test

	High complexity	Low complexity
Chi-square test	0,096525097	0,119682094
Critical value	0,004	

Table 56: presence of a CMMS crossed with the interdependence – comparison with Survey E

	This work		Survey E	
	High interdependence	**Low interdependence**	**High interdependence**	**Low interdependence**
CMMS present	81%	89%	66%	65%
CMMS not adopted	19%	11%	34%	35%

Table 57: presence of a CMMS crossed with the interdependence - comparison with Survey E – Chi-square test

	High interdependence	Low interdependence
Chi-square test	0,10026738	0,253186813
Critical value	0,004	

Table 58: maintenance policy adopted crossed with the technical complexity - comparison with Survey E

	This work		Survey E	
	High complexity	**Low complexity**	**High complexity**	**Low complexity**
Preventive maintenance	27%	30%	50%	46%
Preventive + Predictive maintenance	73%	70%	50%	54%

Table 59: maintenance policy adopted crossed with the technical complexity – comparison with Survey E – Chi-square test

	High complexity	Low complexity
Chi-square test	0,2116	0,10305958
Critical value	0,004	

Table 60: maintenance policy adopted crossed with the interdependence- comparison with Survey E

	This work		**Survey E**	
	High interde-pendence	**Low interde-pendence**	**High interde-pendence**	**Low interde-pendence**
Preventive maintenance	**44%**	38%	**43%**	53%
Preventive + Predictive maintenance	**56%**	63%	**57%**	47%

Table 61: maintenance policy adopted crossed with the interdependence – comparison with Survey E – Chi-square test

	High interde-pendence	**Low interde-pendence**
Chi-square test	0,2116	0,10305958
Critical value	0,004	

From the comparison it is possible to observe a certain similarity between the results of this work and those of the survey E. In some cases (in bold) the percentages are almost coincident and in general the trend is the same. For example, analyzing the presence of the CMMS correlated with the interdependence of the production processes, even if frequencies are different, in both surveys the CMMS adoption result substantially independent of the technical complexity. The results of the chi-square test show in two cases (those in bold text) that the observed frequencies do not differ significantly from the expected frequencies (the null hypothesis is accepted).

In conclusion, this validation phase has highlighted that many results found in this work are substantially aligned with the results of other works. Even if a perfect match of the frequencies is not always reached (Chi square test), however the general trends are the same. Because of the need to adopt a non-probabilistic sampling (convenience sampling), only this qualitative approach has been used to validate the results collected.

8. Second aim

This chapter deals with the second aim exposed in the Chapter 1.2: "*assess if companies, that have implemented integrated solutions for maintenance, use them along the lifecycle of their production plant*".

To do this, it was considered appropriate to carry out an horizontal analysis, in order to evaluate the simultaneous presence of different areas along the horizontal axis of the reference model (therefore their presence in different phases of the plant lifecycle).

In this chapter the answers to the following questions have been considered:

- question n°22bis, concerning the adoption of DFR/DFA techniques;
- question n°26, only for what concerns the current level of implementation of the various areas of the reference model;
- question n°29, only for what concerns the current level of implementation of special purpose software;
- question 31, only for what concerns the current level of implementation of the information flows of the reference model.

All the information coming from these questions have been correlated with the question n°8 that ask which phases of the plant lifecycle (design, construction, operation, revamping) is directly managed by the company.

8.1 Integrated implementation of areas along the plant lifecycle

This section consists of two parts:

- into the first the simultaneous presence of some areas along the horizontal axis of the reference model will be analyzed (the so-called horizontal analysis);
- into the second it will be investigated whether there is a link between the level of implementation of these areas and the phases of the plant lifecycle that involve directly the company.

The following combinations of areas simultaneously implemented have been chosen:

- MED+MEO - to understand if all the results obtained by the maintenance engineering process during the design phase are then taken into account by the same process during the operational phase;
- DDD+MMO - to understand if all the information related to the plant design are recorded into the CMMS;
- DDD+MEO - to understand if all the considerations and studies conducted by the design area are then used by the maintenance engineering during the operational phase;
- DDD+DDR - to understand if all the parameters set during the design phase are employed during the revamping process.

The following table summarizes the results of the implementation level of the four couples of areas above listed:

Table 62: simultaneous presence of the following areas (percentage of companies)

	Whole sample	Paper sector	Chemical/pharmaceutical sector
MED + MEO	12%	14%	10%
DDD + MMO	24%	14%	33%
DDD + MEO	26%	24%	29%
DDD + DDR	24%	14%	33%

In general, the simultaneous presence of different areas is higher in the chemical/pharmaceutical sector; the only exception is represented by the couple MED+MEO that, however, shows very low level of adoption in both sectors.
Therefore, from the perspective of the use of integrated solutions, the results are poor, because no more than one-fourth of companies implements the couples of areas (and this only for companies of the chemical/pharmaceutical sector). From this point of view, it is possible to assert that the level of integration along the plant life cycle is very low.

To confirm this thesis, a further analysis concerning the couples of areas above listed has been carried out: it have been assessed if companies, that implement the various couples of areas, adopt also the related information flow (which is essential for a complete integration of the maintenance system along the plant lifecycle).
The results are as follows:

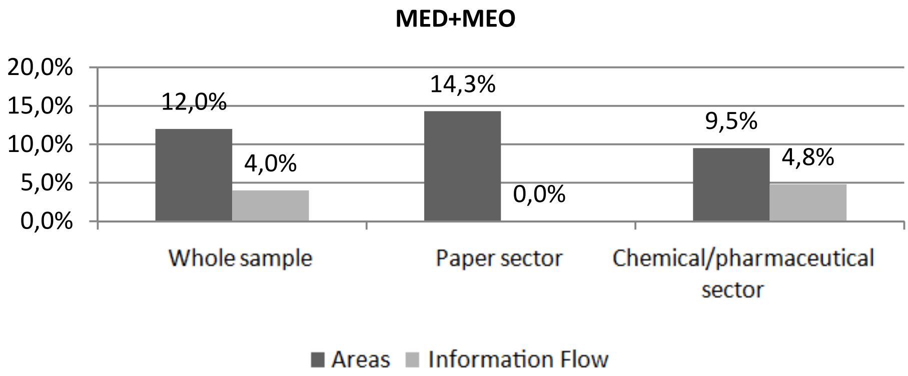


Figure 62: presence of the couple of areas MED+MEO areas and presence of the related flow MED-MEO

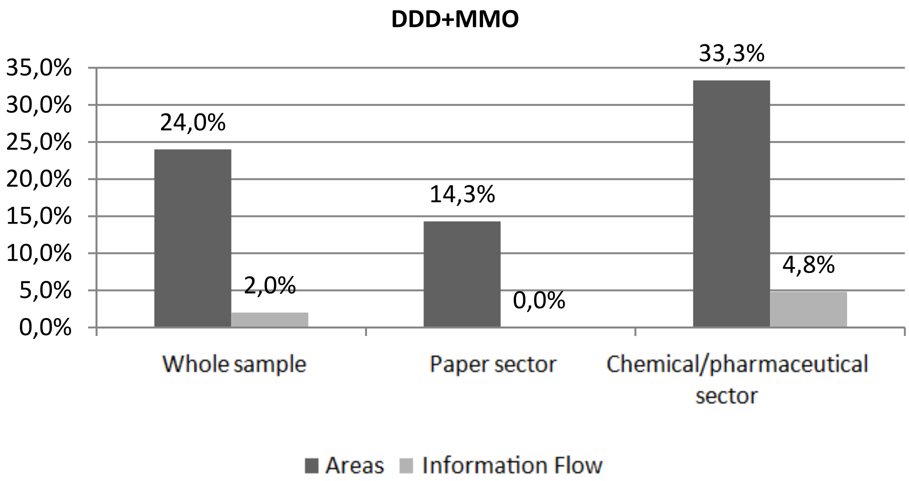


Figure 63: presence of the couple of areas DDD+MMO areas and presence of the related flow DDD-MMO

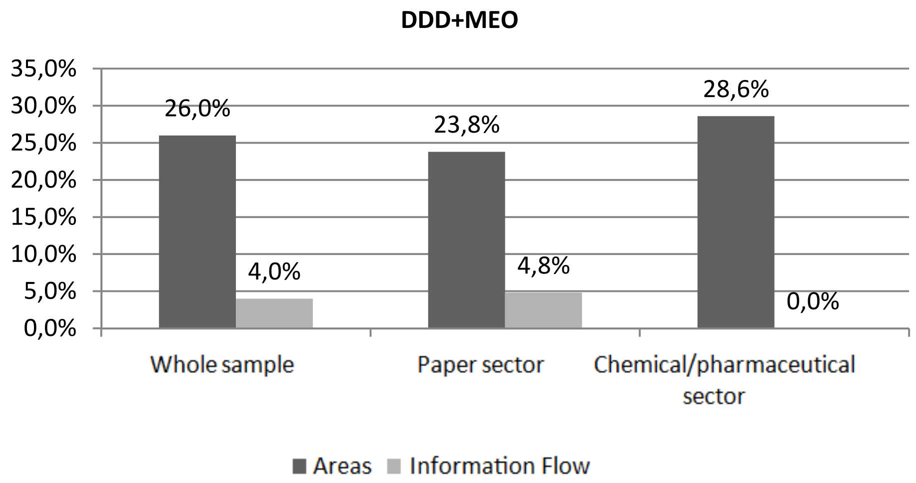


Figure 64: presence of the couple of areas DDD+MEO areas and presence of the related flow DDD-MEO

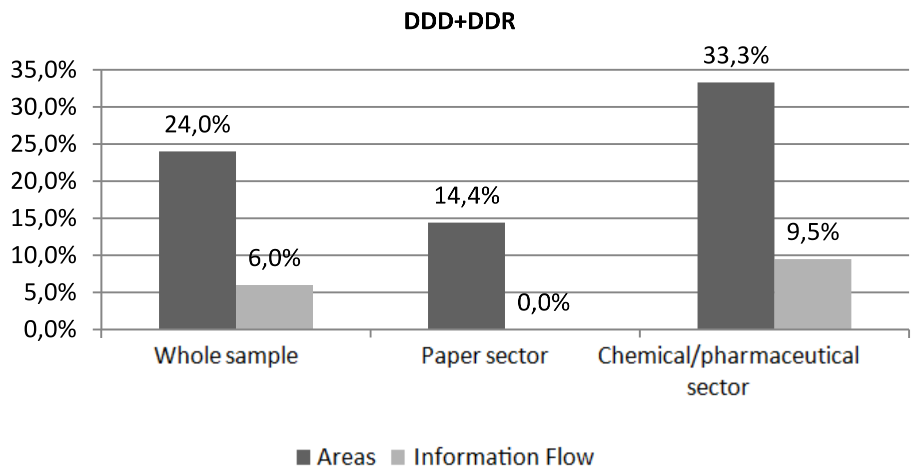
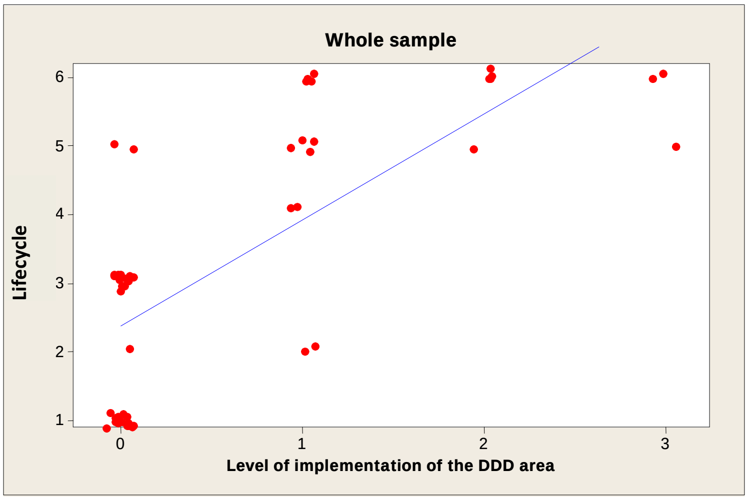


Figure 65: presence of the couple of areas DDD+DDR areas and presence of the related flow DDD-DDR

The percentages observed are very low and confirm what seen in the section 6.3: the knowledge, by the companies, of the importance and usefulness of the information flows (and therefore of the importance of a maintenance system integrated along the plant lifecycle) is very low; often there is a total lack of information flows between the areas. Higher percentages were expected, especially in the chemical/pharmaceutical sector.

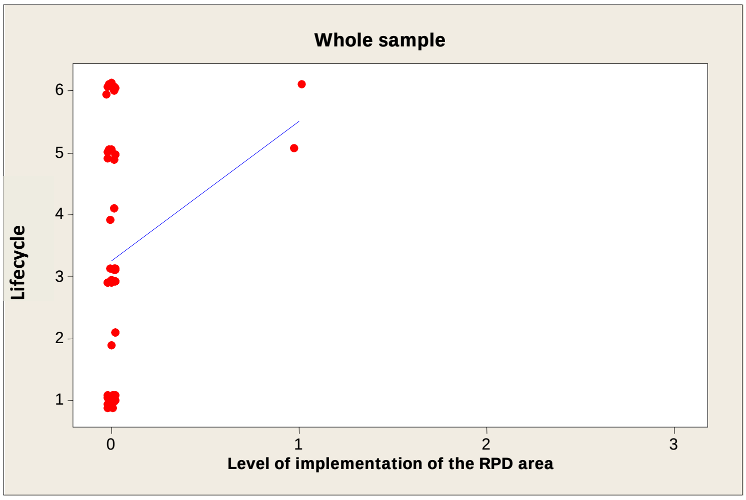
Below, the following scatterplots investigate if there is a correlation between the level of implementation of some areas and the phases of the plant lifecycle that involve directly the company.
The results, obtained with the aid of the software MINITAB 14, are the followings:



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

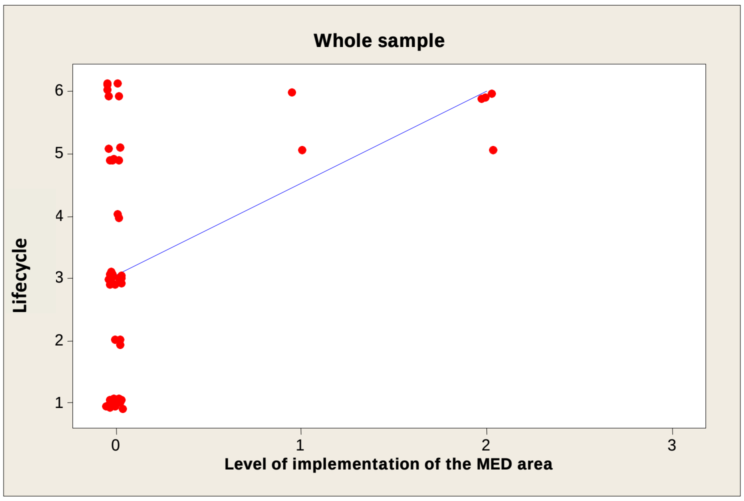
Figure 66: Scatterplot - level of implementation of the DDD area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

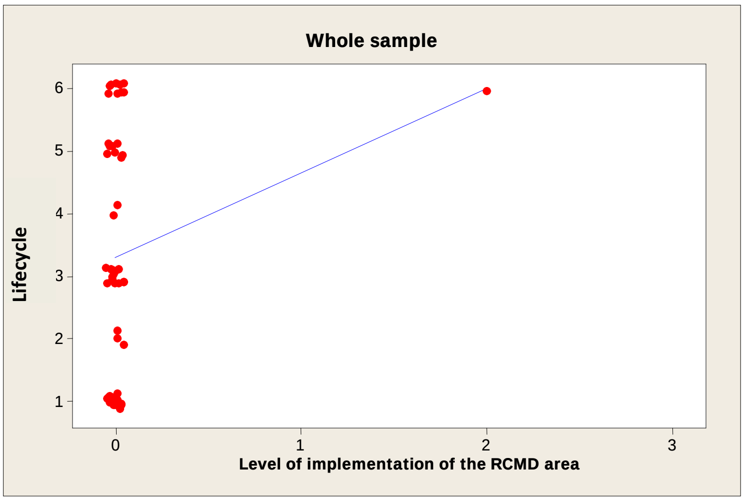
Figure 67: Scatterplot - level of implementation of the RPD area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

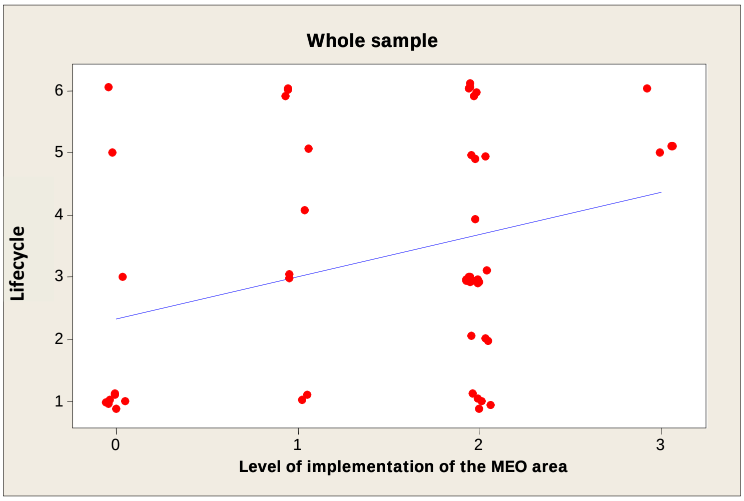
Figure 68: Scatterplot - level of implementation of the MED area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

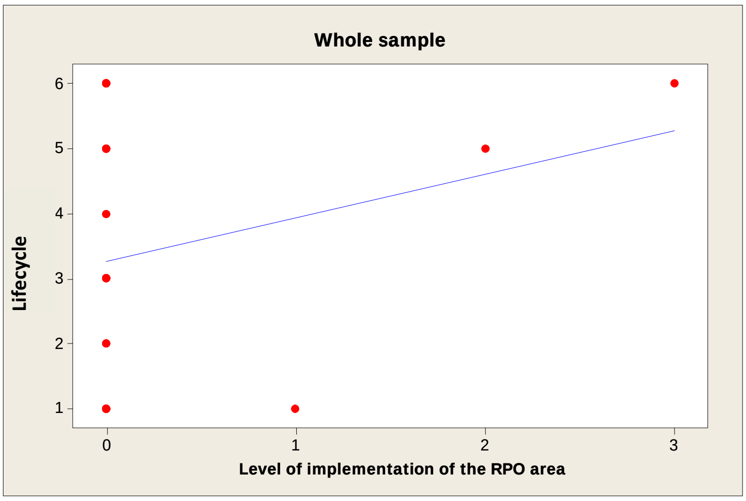
Figure 69: Scatterplot - level of implementation of the RCMD area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

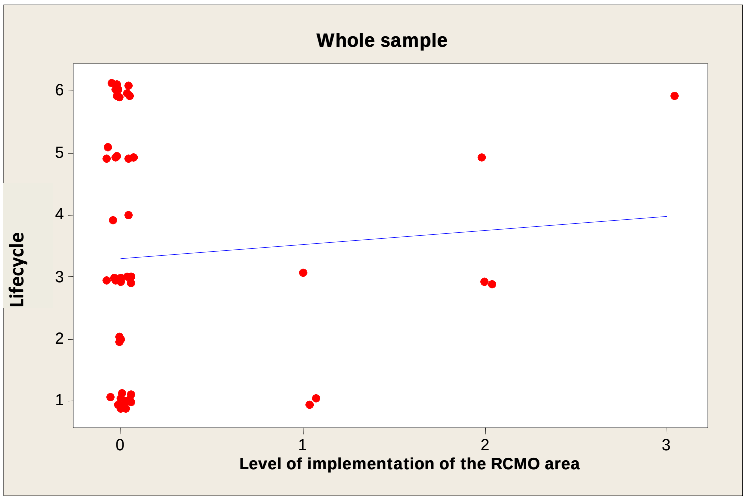
Figure 70: Scatterplot - level of implementation of the MEO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

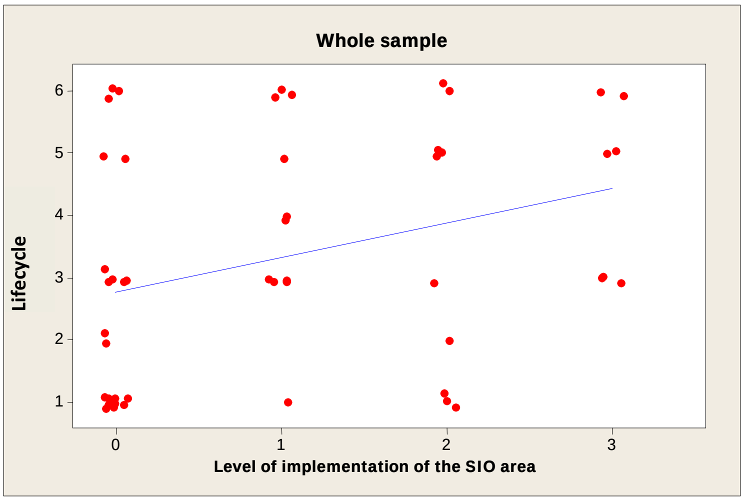
Figure 71: Scatterplot - level of implementation of the RPO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

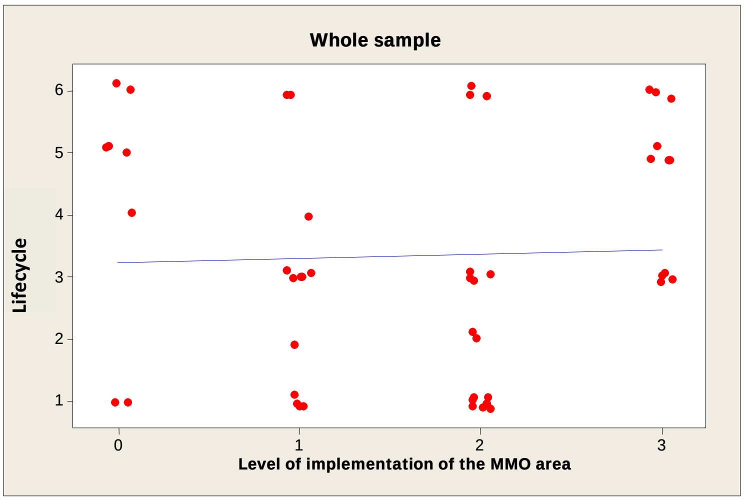
Figure 72: Scatterplot - level of implementation of the RCMO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

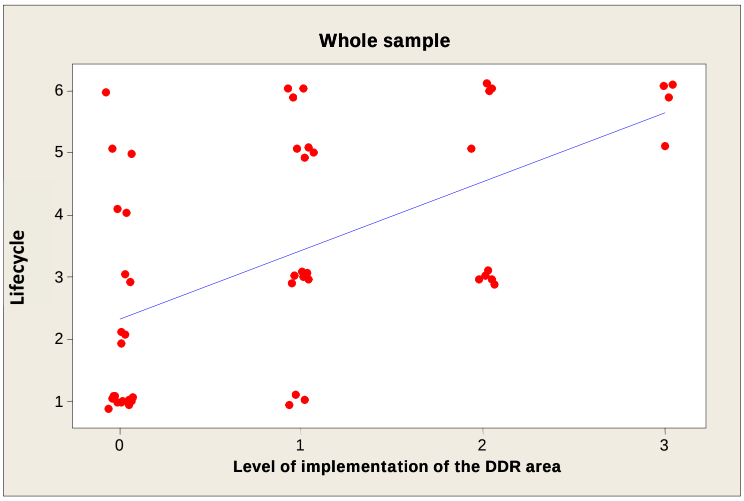
Figure 73: Scatterplot - level of implementation of the SIO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

Figure 74: Scatterplot - level of implementation of the MMO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design+ Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Level of implementation of the area
0. Not present
1. Limited
2. Significant
3. Complete

Figure 75: Scatterplot - level of implementation of the DDR area vs. phases of the plant lifecycle that involve directly the company (Whole sample)

All the scatterplots show a positive correlation between the level of implementation of a single area and the phases of the plant lifecycle that involve directly the company. The most significant results are those related to the following areas:

- DDD: strong positive correlation, observed also analyzing separately the two industrial sectors;
- MEO: the correlation for the paper sector is stronger than that for the chemical/pharmaceutical sector;
- SIO: the correlation is positive for both the sectors;
- MMO: The correlation is positive for both, but stronger for the chemical/pharmaceutical sector;
- DDR: the correlation is strongly positive for both the sectors.

These five areas are also the most implemented. It should be noted, in fact, that some correlations identified, even if with a low p-value, are not very significant because are adopted by few companies (such as the RPD, RPO and RCMD areas).

Table 63: number of companies that implement the following areas

	RPD	MED	**RCMD**	DDD	MEO	**RPO**	RCMO	SIO	MMO	DDR
Whole sample	**2**	6	**1**	19	40	**3**	7	28	41	29
Paper sector	**0**	**3**	**0**	9	19	**1**	**1**	15	15	9
Chemical/pharmaceutical sector	**0**	**2**	**1**	8	15	**1**	**4**	8	19	16

Excluding the RPD and RCMD areas (low implementation), the areas with a positive correlation more pronounced are DDD, DDR and MED (all strictly related to the design of the plant or to its revamping). The design activities, that require high skills, are mostly implemented by those companies that manage large part of the plant life cycle.

To understand which elements have a low level of significance, the Pearson correlation coefficient and the P-value have been calculated through the use of the software Minitab14:

Table 64: correlation between the level of implementation of the following areas and the phases of the plant life-cycle that involve directly the company (whole sample)

	Plant Lifecycle									
	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
Pearson correlation coefficient	0,234	**0,443**	0,202	**0,732**	**0,325**	0,185	0,08	**0,323**	0,04	**0,56**
P-Value	0,102	**0,001**	0,16	**0**	**0,021**	0,199	0,579	**0,022**	0,785	**0**

The most significative correlations are those between MED, DDD, MEO, DDR, SIO and the plant life cycle. These results are consistent with the considerations just made above and highlight how some areas (such as MED, MEO, DDR and DDD), which are present both in the operational and in the design phase, are very influenced by the involvement of the company in the plant lifecycle.

To further verify these results, a scatterplot has been carried out to assess the relationship between questions 8 and 22a (i.e. between the phases of the plant life cycle that directly involve the company and the use of techniques such as DFR / DFA):

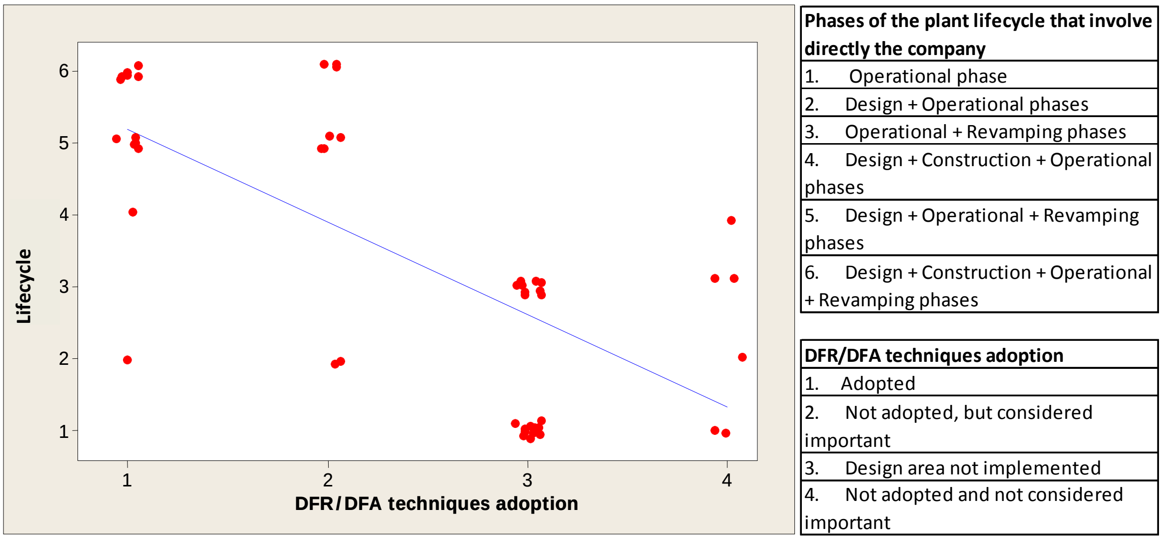
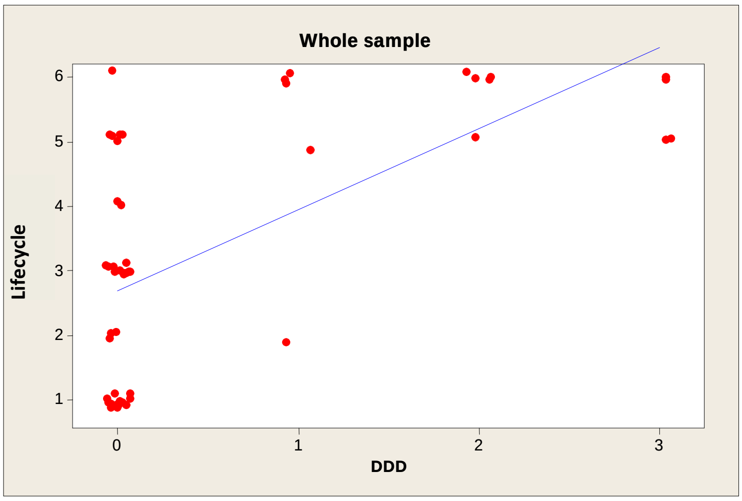


Figure 76: Scatterplot – adoption of DFR/DFA techniques vs. phases of the plant lifecycle that involve directly the company (Whole sample)

Companies that adopt these techniques (and also companies that do not adopt them but consider them important) have an integrated approach along the whole plant lifecycle.

8.2 *Integrated implementation of software along the plant lifecycle*

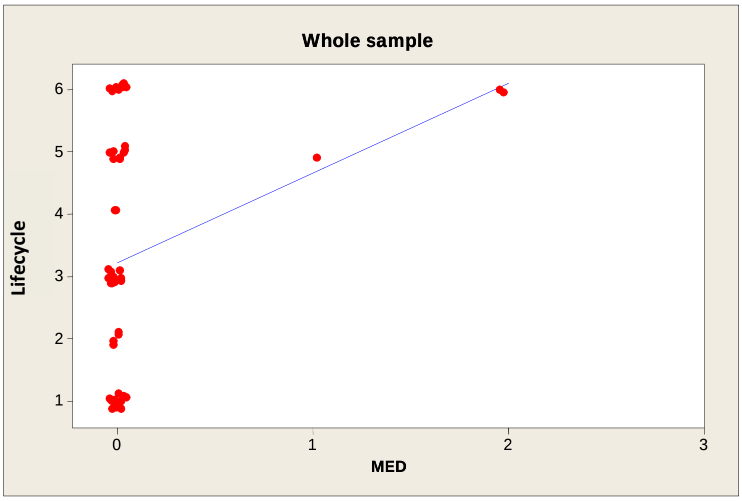
This section deals with the assessment of the correlation between the phases of the life cycle directly managed by the company and the level of implementation of software for the different areas of the reference model.



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

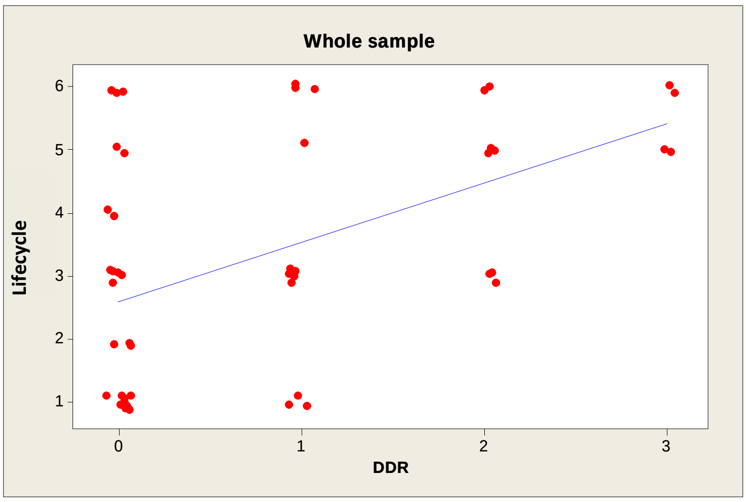
Figure 77: Scatterplot - level of implementation of software for the DDD area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

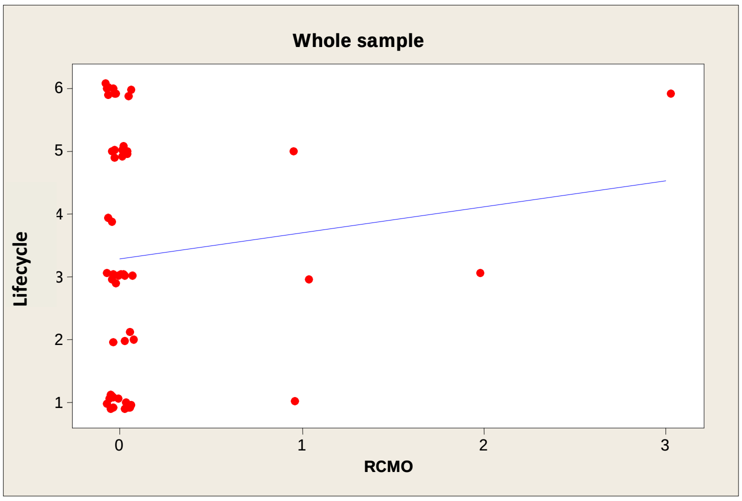
Figure 78: Scatterplot - level of implementation of software for the MED area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

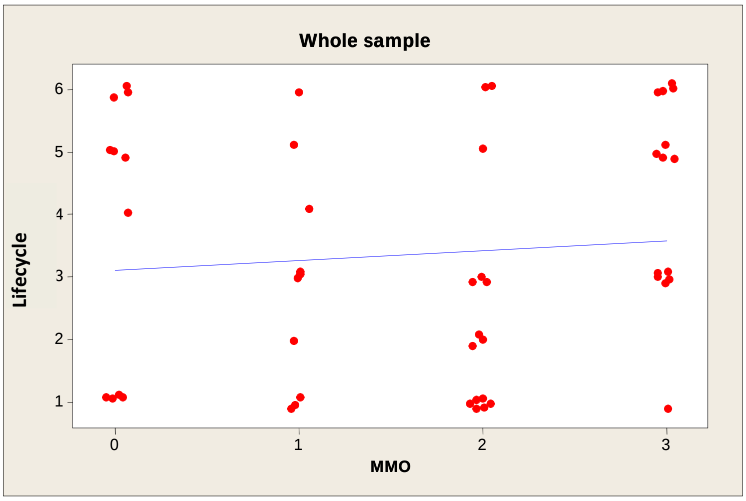
Figure 79: Scatterplot - level of implementation of software for the DDR area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

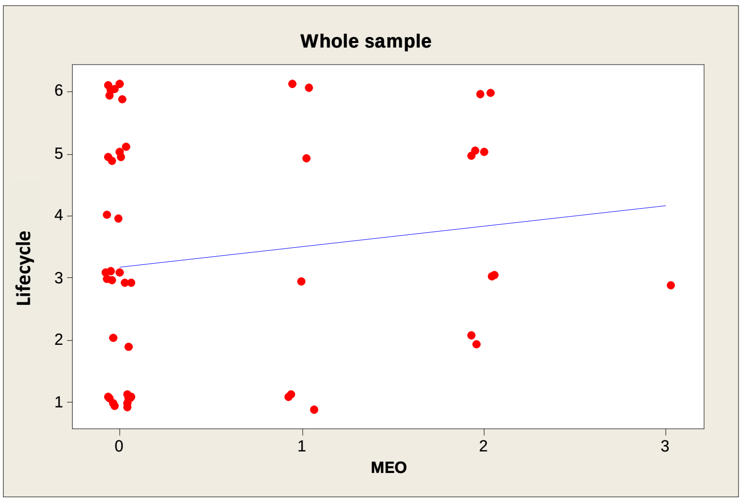
Figure 80: Scatterplot - level of implementation of software for the RCMO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

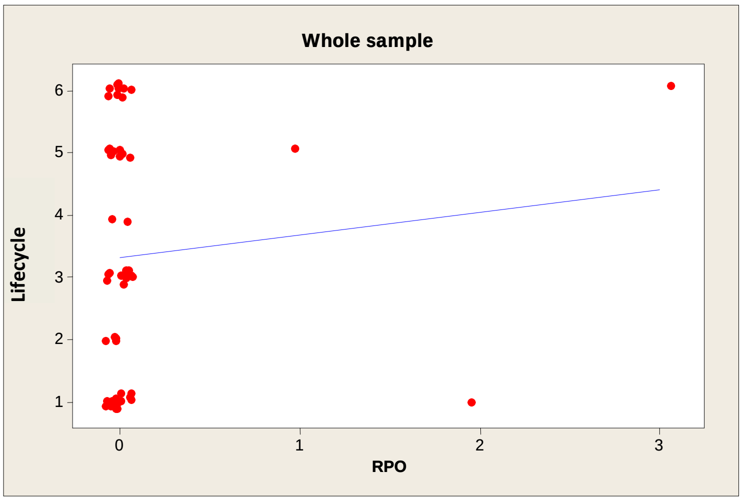
Figure 81: Scatterplot - level of implementation of software for the MMO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

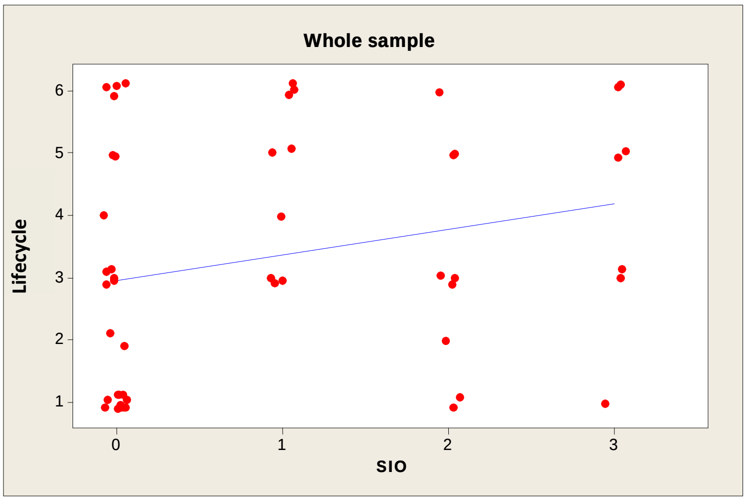
Figure 82: Scatterplot - level of implementation of software for the MEO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 83: Scatterplot - level of implementation of software for the RPO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 84: Scatterplot - level of implementation of software for the SIO area vs. phases of the plant lifecycle that involve directly the company (Whole sample)

In all cases it is observed a positive correlation; analysis on software used in the RPD and RCMD areas were not performed because no one of the companies surveyed adopts them. For each scatterplot the Pearson correlation coefficient and the P-value have been calculated:

Table 65: correlation between the level of implementation of software for the following areas and the phases of the plant lifecycle that involve directly the company (whole sample)

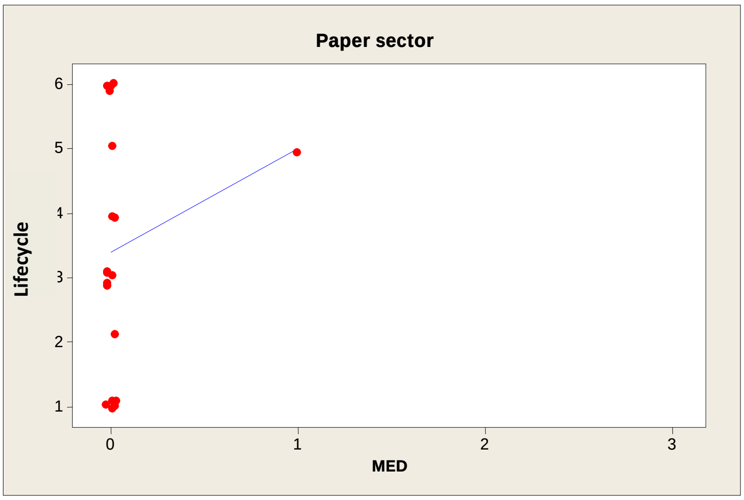
	Plant lifecycle									
	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
Pearson coefficient correlation	-	**0,317**	-	**0,649**	0,156	0,102	0,123	0,245	0,068	**0,492**
P-Value	-	**0,025**	-	**0**	0,281	0,48	0,395	0,086	0,638	**0**

The most significant correlations are those between the level of use of software in the MED, DDD and DDR areas (significance level adopted of 5%) and the phases of the plant life cycle that involve directly the company.
In all these three cases the correlation is positive: companies that manage many phases of the plant life cycle are more inclined to adopt systematically software solutions. The results concerning the DDD and DDR areas are strongly related, considering the similarity of these two areas and the similarity of the software used (usually CAD or derivatives). Interesting is the result concerning the software used for maintenance engineering: previously it was found that the level of implementation of the MEO and MED areas was positively correlated with the lifecycle; for what concerns software, this correlation is found only for MED. Probably the use of software for the maintenance engineering is more pronounced in the design phase, while during the operational phase are more adopted non-standardized methods such as the experience.
To explore in depth these results the same analysis has been performed, distinguishing the two industrial sectors:

Table 66: correlation between the level of implementation of software for the following areas and the phases of the plant lifecycle that involve directly the company (comparison between the two industrial sectors)

	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector
	MED	MED	DDD	DDD	DDR	DDR
Pearson coefficient correlation	0,185	**0,462**	**0,711**	**0,785**	0,341	**0,781**
P-Value	0,422	**0,035**	**0**	**0**	0,13	**0**

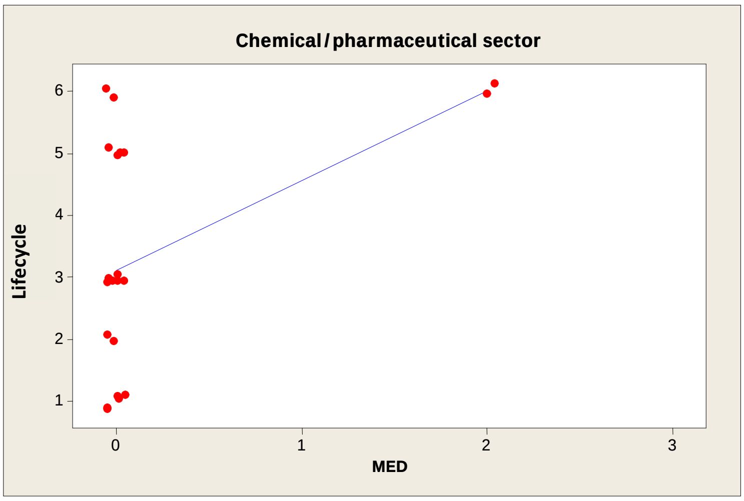
DDR and MED lose significance in the paper industry (considering a significance level of 5%). Limiting the study to the correlation coefficient, it is noted a strong positive correlation between the level of implementation of software in the DDD and DDR areas and the phases of the plant lifecycle directly managed by the company.



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

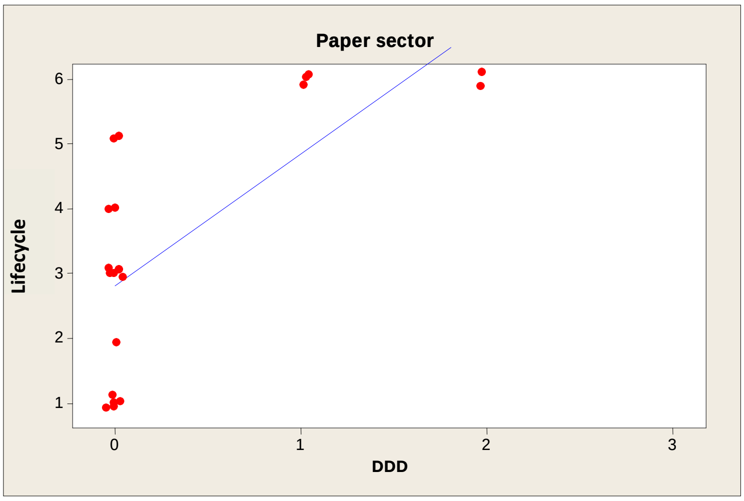
Figure 85: Scatterplot - level of implementation of software for the MED area vs. phases of the plant lifecycle that involve directly the company (Paper sector)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

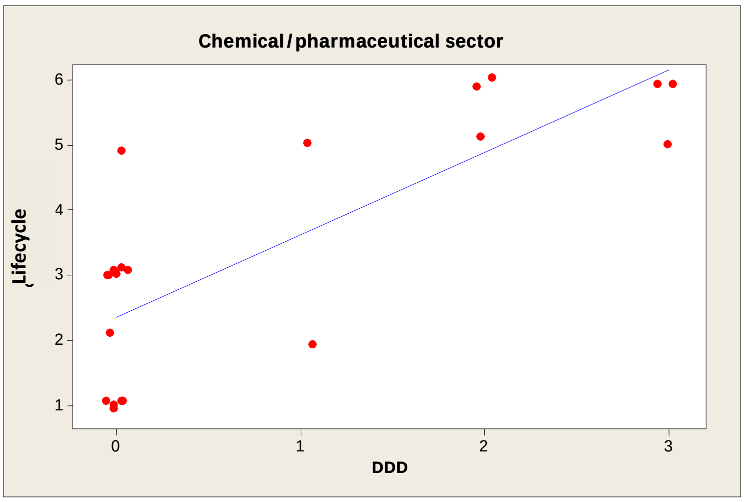
Figure 86: Scatterplot - level of implementation of software for the MED area vs. phases of the plant lifecycle that involve directly the company (Chemical/pharmaceutical sector)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

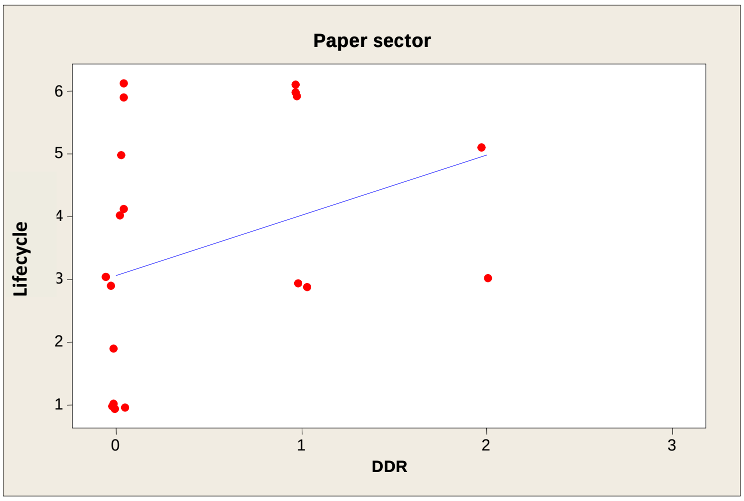
Figure 87: Scatterplot - level of implementation of software for the DDD area vs. phases of the plant lifecycle that involve directly the company (Paper sector)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

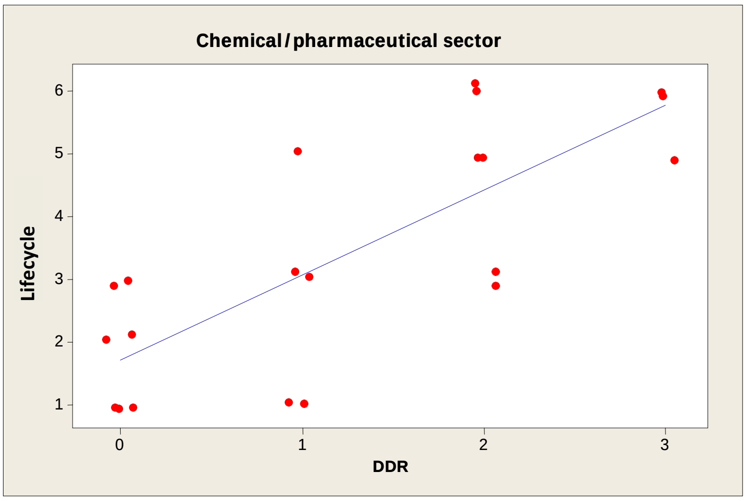
Figure 88: Scatterplot - level of implementation of software for the DDD area vs. phases of the plant lifecycle that involve directly the company (Chemical/pharmaceutical sector)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 89: Scatterplot - level of implementation of software for the DDR area vs. phases of the plant lifecycle that involve directly the company (Paper sector)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of software
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 90: Scatterplot - level of implementation of software for the DDR area vs. phases of the plant lifecycle that involve directly the company (Chemical/pharmaceutical sector)

8.3 Integrated implementation of information flows along the plant lifecycle

In this section is studied the correlations between the level of implementation of information flows and the phases of the plant lifecycle that involve directly the company.
First the Pearson correlation coefficients and the P-values have been calculated, and then the scatterplots of the only flows with significant correlations have been carried out.

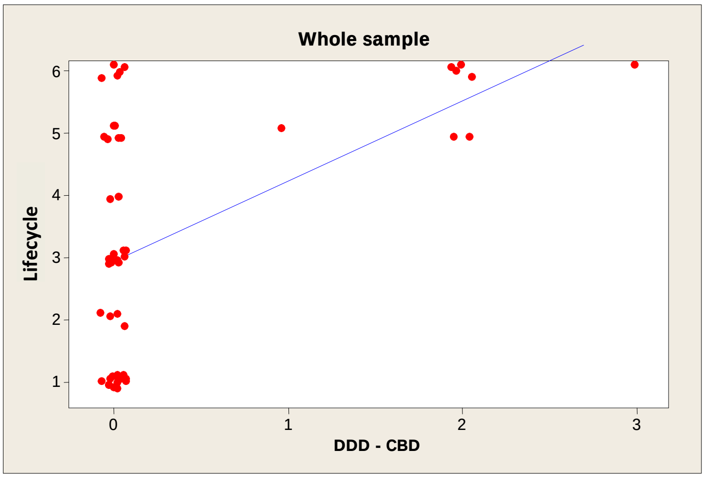
Table 67: correlation between the level of implementation of the following information flows and the phases of the plant lifecycle that involve directly the company (whole sample)

	Plant lifecycle										
	RPD-MED	**MED-DDD**	**DDD-MED**	**MED-RCMD**	**RCMD-DDD**	**DDD-CBD**	**DDD-DD**	**DDD-C**	**C-DDD**	**MED-MEO**	**DDD-MEO**
Pearson coefficient correlation	-	**0,308**	0,017	0,202	0,202	**0,525**	**0,34**	**0,312**	0,24	0,205	0,072
P-Value	-	**0,029**	0,905	0,16	0,16	**0**	**0,016**	**0,027**	0,093	0,154	0,621

	Plant lifecycle									
	DDD-MMO	**DDD-DDR**	**MEO-MMO**	**MMO-MEO**	**MEO-RCMO**	**RCMO-MMO**	**MMO-RCMO**	**MMO-RPO**	**RPO-MEO**	**SIO-MMO**
Pearson coefficient correlation	0,202	0,259	-0,002	0,09	0,196	0,146	0,102	0,102	0,202	0,251
P-Value	0,16	0,07	0,991	0,534	0,172	0,311	0,481	0,481	0,16	0,078

	Plant lifecycle									
	SIO-RPO	**SIO-MEO**	**MMO-DDR**	**SIO-MNT/OP**	**MNT/OP-SIO**	**MMO-MNT/OP**	**MNT/OP - MMO**	**DDR-RVP**	**RVP-DDR**	**MEO-DDR**
Pearson coefficient correlation	0,202	0,173	0,123	0,204	0,268	-0,055	-0,226	**0,314**	0,234	**0,314**
P-Value	0,16	0,229	0,395	0,156	0,059	0,703	0,114	**0,027**	0,102	**0,027**

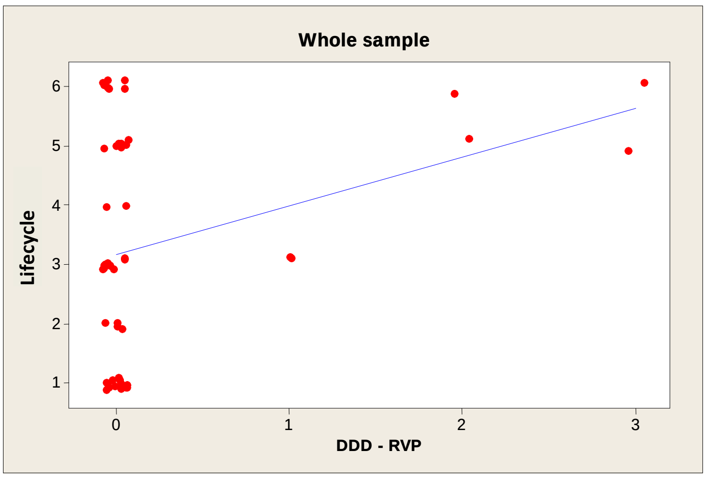
In general, the flows between the most implemented areas don't show any significant correlation with the plant lifecycle, probably because these flows are implemented also by the small and medium enterprises, that typically manage only the operational phase of the plant lifecycle (see for instance the correlation coefficient of the MMO-MEO flow).
The information flows most significant for what concerns the study of the p-value (with a significance level of 5%) are: MED-DDD, DDD-CDB, DDD-DD, DDD-C, DDR-RVP and MEO-DDR:



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

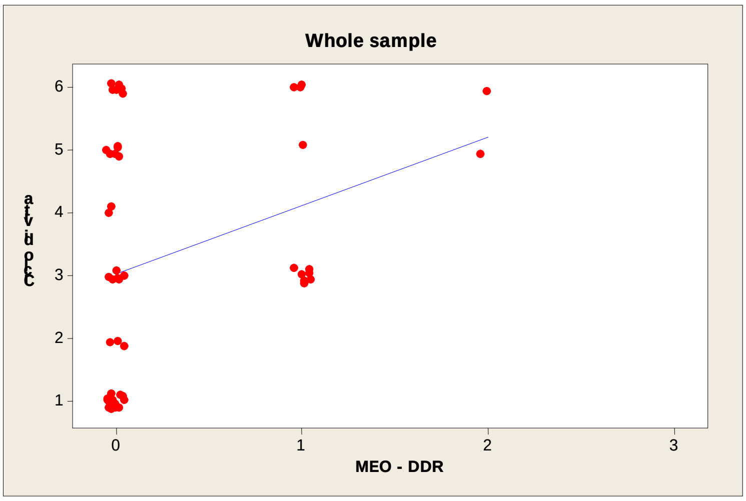
Figure 91: Scatterplot - level of implementation of the information flow DDD-CBD vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

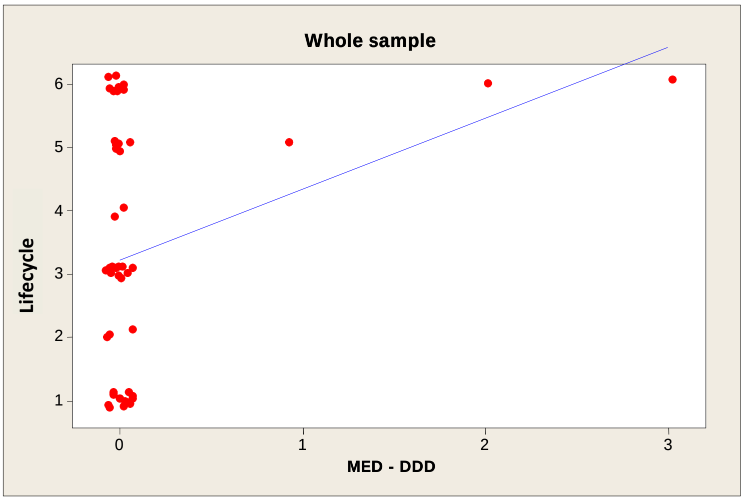
Figure 92: Scatterplot - level of implementation of the information flow DDR-RVP vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

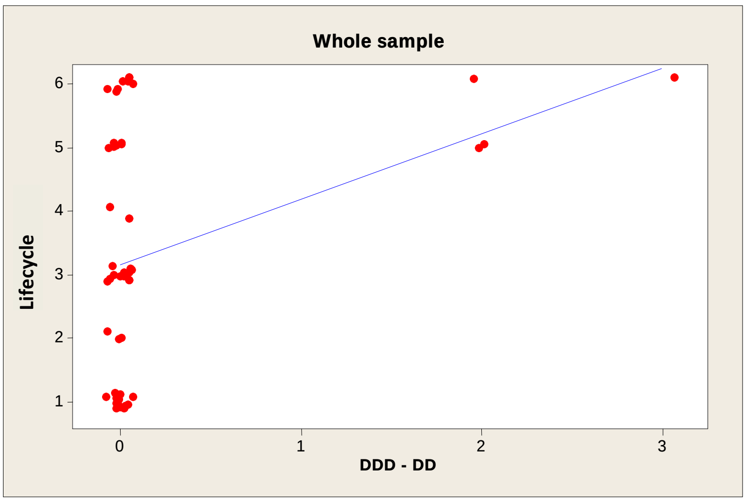
Figure 93: Scatterplot - level of implementation of the information flow MEO-DDR vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

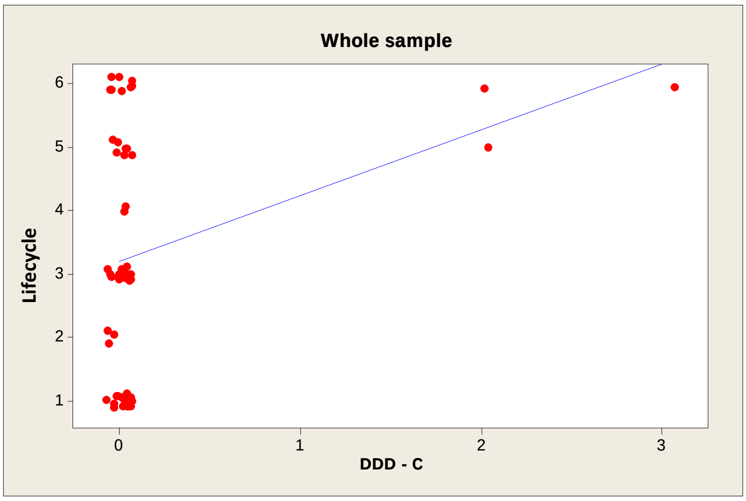
Figure 94: Scatterplot - level of implementation of the information flow MED-DDD vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 95: Scatterplot - level of implementation of the information flow DDD-DD vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

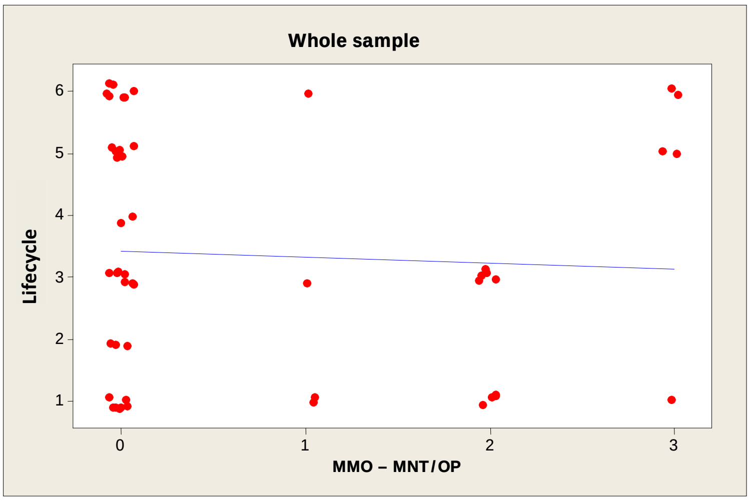
Figure 96: Scatterplot - level of implementation of the information flow DDD-C vs. phases of the plant lifecycle that involve directly the company (Whole sample)

The most significant results are those related to the flows of the DDD and DDR areas. In general, all these flows are poorly implemented, but companies that implement them present medium or high levels of implementation. However, it is not a coincidence that the most significant flows are those of the design system: these are in fact characterized by a strong integration with all data coming from the different areas spread along the plant life-cycle. These six most significant flows have been studied also distinguishing the two industrial sectors:

Table 68: correlation between the level of implementation of the following information flows and the phases of the plant lifecycle that involve directly the company (comparison between the two industrial sectors)

	MED-DDD		DDD-CBD		DDD-DD	
	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector
Pearson correlation coefficient	0,306	0,319	-	**0,771**	-	0,383
P-Value	0,177	0,159	-	**0**	-	0,086
	DDD-C		DDR-RVP		MEO-DDR	
	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector	Paper sector	Chemical/ pharmaceutical sector
Pearson correlation coefficient	-	0,319	-	0,363	0,072	**0,539**
P-Value	-	0,159	-	0,106	0,756	**0,012**

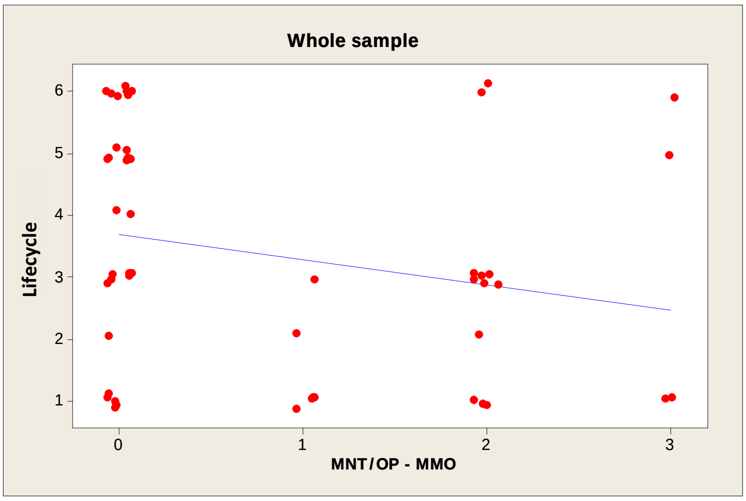
The only flows that maintain significance are the DDD-CBD and MEO-DDR and only in the chemical/pharmaceutical sector. This sector presents in general a level of consistency higher than the paper industry.
It was decided to carry out the scatterplots also of those flows that involve some of the most important areas (considering the whole sample), even if not significant from a statistical point of view:



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

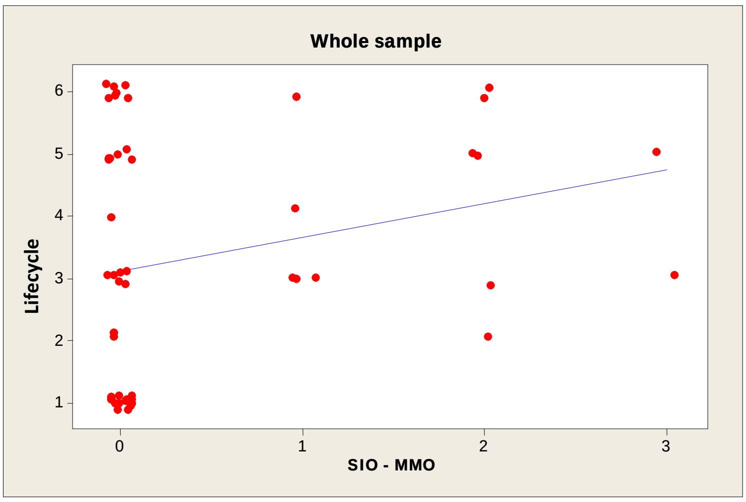
Figure 97: Scatterplot - level of implementation of the information flow MMO-MNT/OP vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 98: Scatterplot - level of implementation of the information flow MNT/OP-MMO vs. phases of the plant lifecycle that involve directly the company (Whole sample)



Phases of the plant lifecycle that involve directly the company
1. Operational phase
2. Design + Operational phases
3. Operational + Revamping phases
4. Design + Construction + Operational phases
5. Design + Operational + Revamping phases
6. Design + Construction + Operational + Revamping phases

Current level of implementation of the information flow
0. Not present
1. Limited use
2. Significant use
3. Systematic use

Figure 99: Scatterplot - level of implementation of the information flow SIO-MMO vs. phases of the plant lifecycle that involve directly the company (Whole sample)

As the number of phases directly managed by company increases, the level of implementation of the flows that link the MMO and MNT/OP areas (in both directions) decreases. while a simultaneous increase of the flows that involve the SIO is observed. Therefore, the information exchanged don't decrease, but follow a different path. Companies that manage a larger part of the plant lifecycle adopt the SIO, which acts as a conduit for the exchange of information between the CMMS and the operational phase.

8.4 Conclusions of the chapter

In conclusion, it can be asserted that the integrated implementation of areas, software and flows along the plant lifecycle is quite low. The chemical/pharmaceutical sector presents a discrete consistency with regard to the horizontal simultaneous implementation of some areas of the reference model. It has been however found a serious shortage, in both the industrial sectors, concerning the comparison between the areas implemented and the related information flows.

To achieve in fact a real integration along the plant lifecycle it is not sufficient to implement simultaneously some areas, but also the relative information flows. This concept is in part respected by the chemical/pharmaceutical companies, but only as regards the design and revamping phases.

In general, all the companies have demonstrated a greater consistency in the vertical analysis performed in the Chapter 6 rather than in this horizontal analysis.

9. Third and fourth aims

This chapter focuses on the third and fourth aims exposed on Section 1.2: "*investigate the correlation among several company's structural variables and the maturity level of adoption of integrated methodologies, approaches and tools for maintenance along the plant lifecycle*" and "*identify the success elements and the barriers that promote or inhibit this integration*".
These two topics will be treated simultaneously.
For the identification of these elements a correlation analysis of some quantitative variables has been performed. The variables considered have been classified into three categories:

- variables related to the company characteristics (the so-called "*company characteristics variables*" - questions from n°3 to n°18);
- variables related to the maintenance strategy, organization, etc… (the so-called "*maintenance variables*" - questions from n°19 to n°27, except n°26);
- variables related to the levels of implementation of flows, areas and software (the so-called "*implementation variables*" - questions n°26, n°29 and n°31).

In this chapter the most significative correlations among these three typologies of variables will be studied:

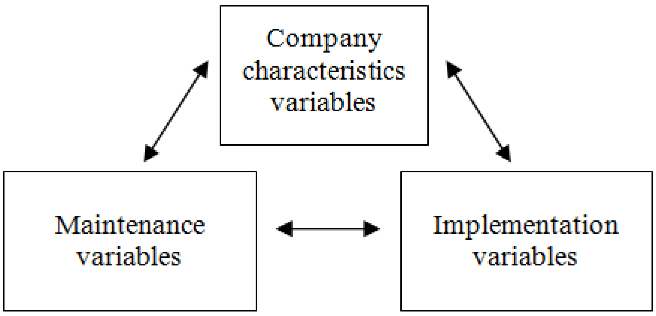


Figure 100: variables classification

The "*company characteristics variables*" identify the company studied in terms of size, industrial sector, manufacturing strategy, technical complexity and so on. The "*maintenance variables*" characterize the company in terms of the maintenance strategy adopted, maintenance workforce, maintenance organization and so on. Finally the "*implementation variables*" identify the company in terms of level of implementation of areas, software and information flows.
The author considered the possibility to conduct a *principal component analysis*, in order to reduce the number of variables. However, this operation resulted not practicable, because of the total diversity of the various questions (diversity not only due to the values assigned to the different answers, which could be eliminated by standardizing the same, but also to the diversity of the logic of value assignment to the different answers).
Therefore the study of the correlations has been performed by the use of *cross tabulation* (where the results are analyzed in relation to their significance expressed by the p-value) for all the quantitative variables and also for the qualitative variables that was possible to convert into quantitative. The correlation between pure qualitative variables have been studied through the *contingency tables analysis*.
The pure qualitative variables studied with the contingency table analysis have been:

- question n°9: plants subjected to special regulamentations;

- question n°10: business strategy adopted;
- question n°19: vertical integration of maintenance;
- question n°20: maintenance as business function of the company;
- question n°21: decentralization of maintenance;
- question n°22: distinction between maintenance engineering and maintenance management;
- question n°22bis: adoption of DFR/DFA techniques.

Even through the analysis of contingency tables it wasn't possible to carry out some considerations about possible correlations between these qualitative variables: the p-values obtained were in fact too high and many cells of this particular analysis were often populated by less than 5 company (dispersed values).
As highlighted in the Chapter 6, some areas present a number of implementations very low, therefore, even if these areas show significant correlations (p-value less than 5%), it is difficult to generalize these results. In the table below is reported the number of companies that have implemented the individual areas (are reported only the areas, because their presence influences the adoption of software and information flows):

Table 69: companies (in number) that have implemented the following areas

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
Whole sample	**2**	6	**1**	19	40	**3**	7	28	41	29
Paper sector	**0**	**3**	**0**	9	19	**1**	**1**	15	15	9
Chemical/pharmaceutical sector	**0**	**2**	**1**	8	15	**1**	**4**	8	19	16

In bold are highlighted those areas implemented by less than 5 companies: for example, it is difficult to carry out generalizations concerning the adoption of RCMD. In fact this area is adopted by only one company of the entire sample.

9.1 Correlations between the company characteristics variables and the maintenance variables

The variables considered to investigate these correlations have been:

- *Quantitative company characteristics variables*:
  - Company size (revenue and workforce);
  - Phases of the plant lifecycle that involve directly the company;
  - Manufacturing strategy;
  - Technical variety:
  - Technical complexity;
  - Interdependence;
  - Equipments average age.

- *Quantitative maintenance variables*:
  - Maintenance strategy;
  - CMMS activities adopted;
  - Human resource.

Table 70: correlation company size - CMMS activities

			CMMS activities										
			Planning and scheduling of work orders	Planning of maintenance activities (preventive and predictive)	Data recording of works performed	Spare parts management (inventory)	Maintenance workforce management	Spare parts management (purchasing)	Maintenance costs budgeting and reporting	Data reporting of maintenance works performed	Data base for availability/reliability analysis	Data base for the optimization of the maintenance policies	Data base for the redesign of components or equipment
Company size	WHOLE SAMPLE	Revenue	0,423 0,002	0,375 0,007	0,499 0	0,234 0,001	0,239 0,095	0,276 0,052	0,335 0,017	0,417 0,003	0,31 0,028	0,398 0,004	0,316 0,025
		Workforce	0,361 0,01		0,317 0,025	0,394 0,005	0,296 0,037	0,395 0,005	0,335 0,017		0,363 0,01	0,309 0,029	0,358 0,011
	PAPER SECTOR	Revenue											
		Workforce											
	C/F SECTOR	Revenue	0,55 0,01	0,466 0,033	0,668 0,001	0,478 0,028	0,518 0,016			0,515 0,017		0,439 0,046	
		Workforce	0,42 0,058				0,639 0,002				0,488 0,025		0,469 0,032

For a better reading of the tables the following format was adopted: each box contains two values, the Pearson correlation coefficient (top) and the P-value (bottom). Boxes with standard characters are those where the p-value is less than 5% and the correlation is positive (those with negative correlation have characters in red) while boxes highlighted in yellow are those characterized by a p-value less than 10%. All the correlations with p-value more than 10% are not reported.

Workforce can be seen as a dependent variable of the revenue. In fact higher is the annual revenue, and consequently greater is the number of engineers, supervisors and maintenance technicians employed.

A revenue high is an important catalyst for the adoption of maintenance planning and control systems (CMMS) and related modules (including those modules that collect data for availability/reliability analysis, optimization of the maintenance policies and redesign of components/equipments). However, this correlation is strongly present only in the chemical/pharmaceutical sector, where on average there is a greater implementation and computerization of areas and information flows (see aim 1).

Another interesting result comes from the analysis of the correlation between annual revenue and degree of involvement of the production operators in preventive maintenance works: higher is the revenue, lower is this involvement. The justification is probably that company with high availability of capitals are equipped with an high number of maintenance technicians, therefore the participation of operators is not required.

Another interesting result is, moreover, the fact that there are no significant correlations between the revenue and the amount in percentage of interventions of corrective, preventive and predictive maintenance. As will be seen below, there is a correlation between the technical variety (equipments diversity, number of OEM, customization, etc.) and the three different types of maintenance policies (this correlation is relevant for the chemical/pharmaceutical sector).

Other considerations could be done studying the correlation between the levels of adoption of the various maintenance policies and the qualitative variables of questions n°9 (special regulamentations) and n°10 (business strategy adopted). However the application of the contingency table analysis did not show any statistical significative correlation (p-values high).
Below is reported one output obtained from the contingency table analysis (performed using Minitab 14):

Table 71: contingency table - correlation business strategy with corrective maintenance

Rows: Business strategy Columns: Corrective maintenance

	1	2	3	All
1	4 0,2600 0,1344	3 0,1400 0,0828	4 -0,4000 -0,1907	11 * *
2	10 -0,8800 -0,268	8 -0,3200 -0,1109	14 1,2000 0,3354	32 * *
3	3 0,6200 0,4019	2 0,1800 0,1334	7 -0,8000 -0,4781	7 * *
All	17 * *	13 * *	20 * *	50

Cell Contents: Count
Residual
Sandardized residual

Pearson Chi-Square = 0,665; DF = 4; P-Value = 0,956
Likelihood Ratio Chi-Square = 0,677; DF = 4; P-Value = 0,954
* NOTE * 6 cells with expected counts less than 5

Table 72: correlation phases of the plant lifecycle that involve directly the company – maintenance strategy, CMMS activities and Human resource

Phases of the plant lifecycle that involve directly the company	Maintenance strategy						CMMS activities				Human resource	
	N° graduated engineers	N° supervisors	N° maintenance technicians	Corrective maintenance	Preventive maintenance	Predictive maintenance	Spare parts management (inventory)	Maintenance workforce management	Maintenance costs budgeting and reporting	Data base for the optimization of the maintenance policies	Training on issues of maintenance (Production operators)	Degree of involvement of production operators in activities of predictive maintenance
WHOLE SMPLE		0,402 0,005	0,331 0,022	-0,314 0,028	0,258 0,073	0,332 0,02		0,326 0,021	0,251 0,079	0,266 0,062		0,244 0,088
PAPER SECTOR	0,435 0,049		0,383 0,087	-0,448 0,041	0,448 0,041	0,481 0,027	0,538 0,012		0,467 0,033		-0,401 0,072	0,447 0,042
C/F SECTOR												

More phases of the plant lifecycle are directly managed by the company and more supervisors and technicians are employed.
The most interesting result emerged, however, is the positive correlation between the phases of the plant lifecycle directly managed and the predictive and preventive maintenance policies adopted (while is observed a negative correlation for the corrective maintenance).
This result agrees with the considerations done in the Chapter 6 (analysis of the first aim) that highlight how to a greater involvement of the companies in the various phases of the plant lifecycle corresponds not only a greater implementation of areas and flows, but also a wider adoption of DFR/DFA techniques. Companies that design their plants with a "reliability and maintenance point of view" are certainly more inclined to adopt preventive or predictive maintenance policies.

Table 73: correlation manufacturing strategy - maintenance strategy and human resource

		Maintenance strategy				Human resource		
Manufacturing strategy		N° supervisors	N° maintenance technicians	Corrective maintenance	Predictive maintenance	Degree of involvement of production operators in resettlement of simple breakdowns	Degree of involvement of production operators in works of preventive maintenance	Degree of involvement of production operators in works of predictive maintenance
WHOLE SAMPLE	Job shop				-0,241 0,095	0,269 0,059		
	Small batch							
	Large batch			-0,246 0,088		-0,268 0,06	-0,263 0,065	
	Continuous process	0,303 0,036	0,292 0,044					
PAPER SECTOR	Job shop							
	Small batch						0,401 0,072	0,5 0,021
	Large batch			-0,499 0,021				
	Continuous process							-0,437 0,048
C/F SECTOR	Job shop							
	Small batch	-0,397 0,075						
	Large batch							
	Continuous process	0,579 0,006						

Table 74: correlation manufacturing strategy - CMMS adopted

			CMMS activities									
			Planning and scheduling of work orders	Planning of maintenance activities (preventive and predictive)	Data recording of works performed	Spare parts management (inventory)	Maintenance workforce management	Spare parts management (purchasing)	Maintenance costs budgeting and reporting	Data reporting of maintenance works performed	Data base for availability/reliability analysis	Data base for the optimization of the maintenance policies
Manufacturing strategy	WHOLE SAMPLE	Job shop								-0,235 0,1		
		Small batch				-0,368 0,009		-0,428 0,002	-0,255 0,073			
		Large batch		0,263 0,065	0,298 0,035					0,252 0,078		
		Continuous process				0,334 0,018	0,344 0,014	0,279 0,05	0,261 0,068			0,247 0,084
	PAPER SECTOR	Job shop										
		Small batch									0,453 0,039	
		Large batch						-0,383 0,087				
		Continuous process									-0,464 0,034	
	C/F SECTOR	Job shop										
		Small batch	-0,397 0,074		-0,51 0,018	-0,642 0,002		-0,667 0,001	-0,406 0,068			
		Large batch										
		Continuous process			0,371 0,098	0,486 0,025	0,483 0,027					

Correlating the variables of the manufacturing strategy with those of the maintenance strategy, the results show that to continuous production processes corresponds a larger number of personnel dedicated to maintenance. This is because continuous processes require high availability of the plant, which can be partially guaranteed by the constant presence of qualified personnel for maintenance. This result is confirmed also by the fact that, passing from job shop to continuous processes, the involvement of production operators in preventive and predictive maintenance activities decreases (because more qualified personnel is required and also because continuous processes are often highly automated and not conducted by operators).
There isn't, instead, a strong correlation between the manufacturing strategy and the maintenance policies adopted. This is probably due to the fact that many companies do not adopt a single manufacturing strategy, but different strategies, highlighting therefore the need for the adoption of an updated and revised version of the Hayes and Wheelwright matrix for the classification of the "manufacturing strategy".
The p-value test shows that only for the paper sector, if a large batch process is adopted, corrective maintenance policies are not used. Adopting a significance level of 10%, the same test shows that for job-shop processes are not adopted policies of predictive mainten-

ance. These results are quite acceptable, however, a significance level of 10% is very high, so the results should be treated very carefully and not be generalized.
Correlating the manufacturing strategy with the maintenance planning and control system (CMMS) is noted that, passing from job shop to continuous processes, the level of implementation of CMMS modules increases, especially for what concerns the "Spare parts management (inventory and purchasing)" and "Maintenance workforce management". This is comprehensible because, as seen before, the implementation of such systems is strongly influenced by the revenue and continuous processes are often present in large companies with high revenues. This correlation is particularly strong for the chemical/pharmaceutical sector.

Table 75: correlation technical variety – maintenance strategy and human resource

		Maintenance strategy						Human resource						
Technical variety		N° graduated engineers	N° supervisors	N° maintenance technicians	Corrective maintenance	Preventive maintenance	Predictive maintenance	Training on issues of maintenance (graduated engineers)	Training on issues of maintenance (supervisors)	Training on issues of maintenance (maintenance technicians)	Training on issues of maintenance (production operators)	Degree of involvement of production operators in resettlement of simple breakdowns	Degree of involvement of production operators in works of preventive maintenance	Degree of involvement of production operators in works of predictive maintenance
WHOLE SAMPLE	Type of production equipment 80% - 20%										0,261 0,067	0,455 0,001		
	Few OEM – Many OEM					-0,321 0,025							-0,297 0,036	
	Standard equipments – customized equipments	0,338 0,019		0,295 0,042	-0,273 0,058	0,38 0,007	0,262 0,069	0,375 0,007						
	Recurrent failures	-0,252 0,084	-0,255 0,08		0,585 0	-0,524 0	-0,314 0,028							
	Unusual failures			-0,244 0,094					-0,24 0,093					
PAPER SECTOR	Type of production equipment 80% - 20%	-0,379 0,09												
	Few OEM – Many OEM													
	Standard equipments – customized equipments	0,475 0,003		0,398 0,074										
	Recurrent failures	-0,373 0,095	-0,39 0,081		0,643 0,002	-0,51 0,018	-0,389 0,081							
	Unusual failures			-0,412 0,064	0,461 0,036		-0,563 0,008							
C/F SECTOR	Type of production equipment 80% - 20%	0,418 0,059	0,521 0,015	0,591 0,005			0,464 0,034	0,407 0,067				0,512 0,018		0.459 0,036
	Few OEM – Many OEM													
	Standard equipments – customized equipments	0,471 0,031			-0,604 0,004	0,51 0,018	0,464 0,034	0,489 0,025						
	Recurrent failures	-0,438 0,047			0,695 0	-0,639 0,002		-0,392 0,079	-0,451 0,04	-0,423 0,056	-0,423 0,056			
	Unusual failures	-0,423 0,056					0,42 0,058	-0,418 0,059	-0,491 0,024					

Table 76: correlation technical variety - CMMS activities

			CMMS activities							
			Planning and scheduling of work orders	Planning of maintenance activities (preventive and predictive)	Data recording of works performed	Spare parts management (inventory)	Maintenance workforce management	Spare parts management (purchasing)	Maintenance costs budgeting and reporting	Data reporting of maintenance works performed
Technical variety	WHOLE SAMPLE	Type of production equipment 80% - 20%		0,265 0,063			0,246 0,085			0,251 0,079
		Few OEM – Many OEM								
		Standard equipments – customized equipments			0,244 0,088	0,277 0,051	0,266 0,062	0,351 0,013		
		Recurrent failures		-0,305 0,031						
		Unusual failures								
	PAPER SECTOR	Type of production equipment 80% - 20%								
		Few OEM – Many OEM								
		Standard equipments – customized equipments								
		Recurrent failures	-0,415 0,061	-0,443 0,044		-0,423 0,056	-0,427 0,053			
		Unusual failures								
	C/F SECTOR	Type of production equipment 80% - 20%	0,425 0,055			0,429 0,052	0,534 0,013			0,378 0,091
		Few OEM – Many OEM							0,462 0,035	
		Standard equipments – customized equipments		0,397 0,075						
		Recurrent failures								
		Unusual failures	0,494 0,023				0,456 0,038			

As described in the previous chapters, the questionnaire developed has many point in common with the questionnaire designed by Laura Swanson [33]. Swanson, basing on her data (sample composed by North America companies), shows that there are no significant correlations between the technical variety and the adoption of specific maintenance policies.
In this case the results show that, for the whole sample and the paper industry, the correlation between technical variety and maintenance policies is not strong, while it is evident for the chemical/pharmaceutical sector. In this sector, in fact, it is observed that to a greater variety of equipments correspond an higher adoption of predictive techniques, and to a greater customization of equipments corresponds a lower adoption of corrective maintenance. Additionally, in this sector is observed a larger implementation of CMMS modules with the increasing of the technical variety. This different behavior of the chemical/pharmaceutical

sector is mainly due to the fact that companies of this sector present a greater level of technical variety.
In accordance to Swanson, also in this work any significant correlation between the technical variety and the decentralization of maintenance has been found: through the correlation analysis (cross-tabulation) it was not possible to make further considerations because the values identified were not significant (p-value over 5%). To overcome this problem, a principal component analysis was performed but the results were the same.

Table 77: correlation technical complexity - maintenance strategy and CMMS activities

			Maintenance strategy						CMMS activities			
			N° graduated engineers	N° supervisors	N° maintenance technicians	Corrective maintenance	Preventive maintenance	Predictive maintenance	Planning and scheduling of work orders	Data recording of works performed	Spare parts management (purchasing)	Data base for the optimization of the maintenance policies
Technical complexity	WHOLE SAMPLE	Time needed to identify the failure										
		Time needed to prepare the intervention			-0,294 0,043							
		Time needed to repair the failure		-0,254 0,082	-0,321 0,026							-0,327 0,021
		Time needed to restart the plant										
		Machines that implement flexible integrated automation	0,263 0,071			-0,245 0,089		0,307 0,032				
	PAPER SECTOR	Time needed to identify the failure					-0,486 0,025					
		Time needed to prepare the intervention		-0,41 0,065								
		Time needed to repair the failure			-0,375 0,094						0,443 0,044	-0,394 0,077
		Time needed to restart the plant	0,42 0,058	0,381 0,089	0,467 0,033			0,512 0,018				
		Machines that implement flexible integrated automation				-0,41 0,065						
	C/F SECTOR	Time needed to identify the failure							-0,464 0,034			
		Time needed to prepare the intervention										
		Time needed to repair the failure								-0,448 0,042		
		Time needed to restart the plant										
		Machines that implement flexible integrated automation	0,377 0,092									

Table 78: correlation technical complexity - human resource

Technical complexity		Human resource					
		Training on issues of maintenance (graduated engineers)	Training on issues of maintenance (production operators)	Degree of involvement of production operators in routine maintenance interventions	Degree of involvement of production operators in resettlement of simple breakdowns	Degree of involvement of production operators in works of preventive maintenance	Degree of involvement of production operators in works of predictive maintenance
WHOLE SAMPLE	Time needed to identify the failure				-0,25 0,08		
WHOLE SAMPLE	Time needed to prepare the intervention				-0,341 0,015		
WHOLE SAMPLE	Time needed to repair the failure				-0,238 0,096	-0,241 0,092	
WHOLE SAMPLE	Time needed to restart the plant		-0,275 0,053		-0,292 0,04	-0,399 0,004	
WHOLE SAMPLE	Machines that implement flexible integrated automation	0,247 0,083					
PAPER SECTOR	Time needed to identify the failure		-0,378 0,092		-0,442 0,045	-0,382 0,088	
PAPER SECTOR	Time needed to prepare the intervention						
PAPER SECTOR	Time needed to repair the failure						
PAPER SECTOR	Time needed to restart the plant				-0,394 0,077		
PAPER SECTOR	Machines that implement flexible integrated automation						
C/F SECTOR	Time needed to identify the failure			-0,386 0,084	-0,487 0,025		-0,375 0,093
C/F SECTOR	Time needed to prepare the intervention				-0,43 0,052		
C/F SECTOR	Time needed to repair the failure						
C/F SECTOR	Time needed to restart the plant					-0,548 0,01	-0,526 0,014
C/F SECTOR	Machines that implement flexible integrated automation	0,543 0,011					

Strong positive correlations between the technical complexity and the others variables are not observed (in this work the technical complexity is intended as the average time needed to identify the failure, prepare the intervention, repair the failure and restart the plant and as the percentage of machines that implement flexible integrated automation).

What emerges from the analysis is that, where an increasing technical complexity is observed, a certain tendency to adopt predictive maintenance and invest more time in the training is noted.

Table 79: correlation interdependence - maintenance strategy and CMMS activities

			Maintenance strategy					CMMS activities				
			N° graduated engineers	N° maintenance technicians	Corrective maintenance	Preventive maintenance	Predictive maintenance	Maintenance workforce management	Maintenance costs budgeting and reporting	Data reporting of maintenance works performed	Data base for availability/reliability analysis	Data base for the redesign of components or equipment
Interdependence	WHOLE SAMPLE	Presence/absence of buffer stocks	0,242 0,097					-0,299 0,035				
		Rerouting work is possible/ not possible		-0,285 0,05		0,304 0,034	-0,289 0,044				-0,282 0,047	
		Rigid/flexible production flow						-0,268 0,06				-0,255 0,074
		Percentage of production process phases that stop within the first hour of if a singular machine breakdown occurs			0,258 0,074	-0,313 0,028	-0,423 0,002					
	PAPER SECTOR	Presence/absence of buffer stocks										
		Rerouting work is possible/ not possible				0,374 0,095						
		Rigid/flexible production flow										
		Percentage of production process phases that stop within the first hour of if a singular machine breakdown occurs			0,407 0,067		-0,539 0,012					
	C/F SECTOR	Presence/absence of buffer stocks						-0,442 0,045				
		Rerouting work is possible/ not possible		-0,46 0,036					0,53 0,013			
		Rigid/flexible production flow										
		Percentage of production process phases that stop within the first hour of if a singular machine breakdown occurs					-0,587 0,005			-0,4 0,072		

Table 80: correlation interdependence - human resource

			Human resource			
			Training on issues of maintenance (maintenance technicians)	Training on issues of maintenance (graduated engineers)	Degree of involvement of production operators in works of preventive maintenance	Degree of involvement of production operators in works of predictive maintenance
Interdependence	WHOLE SAMPLE	Presence/absence of buffer stocks		0,262 0,066		
		Rerouting work is possible/ not possible				
		Rigid/flexible production flow				
		Percentage of production process phases that stop within the first hour of if a singular machine breakdown occurs				

PAPER SECTOR	Presence/absence of buffer stocks				
	Rerouting work is possible/ not possible			0,374 0,095	
	Rigid/flexible production flow			0,554 0,009	
	Percentage of production process phases that stop within the first hour of if a singular machine break-down occurs	-0,408 0,066			-0,433 0,05
C/F SECTOR	Presence/absence of buffer stocks				
	Rerouting work is possible/ not possible				
	Rigid/flexible production flow				
	Percentage of production process phases that stop within the first hour of if a singular machine break-down occurs				

Also the analysis of correlations between interdependence and other variables has provided few results. Looking at the whole sample can be seen that to an increasing interdependence corresponds a greater adoption of preventive maintenance policies (but not predictive). This behavior is partly visible in the paper sector (using a significance level of 10%), but not in the chemical/pharmaceutical sector.

Table 81: correlation equipments average age - maintenance stratey, CMMS activities and human resource

		Maintenance strategy			CMMS activities		Human resource			
		N° graduated engineers	Corrective maintenance	Preventive maintenance	Maintenance workforce management	Spare parts management (purchasing)	Training on issues of maintenance (graduated engineers)	Training on issues of maintenance (maintenance technicians)	Training on issues of maintenance (production operators)	Degree of involvement of production operators in routine maintenance interventions
Equipments average age	WHOLE SAMPLE	-0,368 0,01		-0,429 0,002			-0,412 0,003	-0,278 0,051		
	PAPER SECTOR	-0,394 0,077	0,382 0,088	-0,477 0,029						-0,391 0,079
	C/F SECTOR	-0,39 0,081		-0,554 0,009	0,428 0,053	0,383 0,087	-0,577 0,006	-0,442 0,045	-0,442 0,045	

For the whole sample, to a greater age of the equipments correspond a lower activity of preventive maintenance and a lower training of engineers, technicians and operators.
This result is understandable because, especially in the paper sector, the authors has found situations with equipment older than 50 years, where the typologies of failure are well known and it is very hard to insert modern equipment to monitor all the parameters useful for the predictive maintenance.

9.2 *Correlations between the company characteristics variables and the implementation variables*

The variables considered into this section are:

- *Quantitative company characteristics variables*:
  - Company size (revenue and workforce);
  - Phases of the plant lifecycle that involve directly the company;
  - Manufacturing strategy;
  - Technical variety:
  - Technical complexity;
  - Interdependence;
  - Equipments average age.
- *Quantitative implementation variables*:
  - Level of implementation of the reference model areas;
  - Level of implementation of the related software;
  - Level of implementation of the related information flows.

Table 82: correlation levels of implementation - company size

		Company size					
		WHOLE SAMPLE		PAPER SECTOR		C/F SECTOR	
		Revenue	Workforce	Revenue	Workforce	Revenue	Workforce
Implementation of areas	MED	0,318 0,025		0,509 0,019			
	RPO	0,321 0,023					
	RCMO	0,316 0,025	0,28 0,048				
	SIO	0,309 0,029	0,324 0,022	0,385 0,085			
	MMO	0,467 0,001	0,519 0	0,485 0,026	0,505 0,02		
	DDR	0,298 0,035	0,276 0,052				
Implementation of software	MED	0,294 0,039					
	DDD	0,267 0,061					
	MEO	0,412 0,003	0,291 0,041	0,781 0	0,546 0,01		
	RPO	0,345 0,014	0,284 0,046		0,543 0,011		
	RCMO	0,352 0,012	0,247 0,084		0,543 0,011		
	SIO	0,279 0,049	0,275 0,053			0,402 0,071	0,485 0,026
	MMO	0,498 0	0,516 0	0,409 0,065	0,444 0,044	0,552 0,009	0,498 0,021
	DDR	0,377 0,007	0,364 0,009		0,481 0,027		
Implementation of information flows	DDD-CBD		0,255 0,074				
	DDD-DD		0,323 0,022				0,495 0,023
	DDD-C		0,247 0,083				
	C-DDD		0,305 0,031				
	MED-MEO		0,236 0,1				
	DDD-DDR	0,266 0,062	0,356 0,011				0,506 0,019

	MEO-MMO	0,405 0,004	0,249 0,081		0,543 0,011		
	MMO-MEO	0,427 0,002		0,631 0,002	0,422 0,056	0,405 0,069	
	MEO-RCMO	0,268 0,06			0,543 0,011		
	MMO-RPO	0,306 0,031					
	SIO-MMO	0,313 0,027		0,398 0,074			0,519 0,016
	SIO-MNT/OP	0,333 0,018	0,421 0,002				0,506 0,019
	MNT/OP-SIO		0,326 0,021				0,402 0,071
	MMO-MNT/OP	0,244 0,088	0,315 0,026				
	DDR-RVP		0,335 0,017				0,507 0,019
	RVP-DDR		0,311 0,028				
	MEO-DDR	0,28 0,049					

A strong correlation between the company size (in terms of revenue and workforce) and the level of implementation of areas, software and information flows is observed; in particular, the revenue appears to be the most significant element, especially for what concerns the whole sample.

Comparing the two industrial sectors, it is observed that in the paper sector the main driver is the revenue, while in the chemical/pharmaceutical sector is the workforce: considering the fact that in the chemical/pharmaceutical sector the level of adoption of areas, software and flows is higher than in the paper sector, this result shows that a greater number of employees encourages the implementation of maintenance tools (this is confirmed by the correlation between the level of implementation of these instruments and the number of specialized technicians involved in maintenance). Analyzing in more detail these results, it is observed that the revenue is positively correlated with the level of adoption of areas of the operational phase, while for what concerns the design phase, only the Engineering Maintenance activity (MED) is significantly correlated with the company size. Even more evident is the positive correlation between the company size and the level of adoption of software: the highest values of these coefficients have been found for software adopted in the MEO and MMO areas. From the point of view the information flows, assume particular significance those flows directly involved in the production activity and in the supervisory control systems (respectively MNT/OP and SIO).

Table 83: correlation levels of implementation - phases of the plant lifecycle that involve directly the company

		Phases of the plant lifecycle that involve directly the company		
		WHOLE SAMPLE	PAPER SECTOR	C/F SECTOR
Implementation of areas	MED	0,443 0,001	0,45 0,041	
	DDD	0,732 0	0,782 0	
	MEO	0,325 0,021	0,411 0,064	
	SIO	0,323 0,022		
	DDR	0,56 0	0,5151 0,017	
Implementation of software	MED	0,317 0,025		
	DDD	0,649 0	0,711 0	

	SIO	0,245 0,086		
	DDR	0,492 0		
Implementation of information flows	MED-DDD	0,308 0,029		
	DDD-CBD	0,525 0		
	DDD-DD	0,34 0,016		
	DDD-C	0,312 0,027		
	C-DDD	0,24 0,093		
	DDD-DDR	0,259 0,07		
	SIO-MMO	0,251 0,078		
	MNT/OP-SIO	0,268 0,059		
	DDR-RVP	0,314 0,027		
	MEO-DDR	0,314 0,027		0,42 0,058

Differently than expected, for the chemical/pharmaceutical sector (and also for the paper sector) the correlations between the phases of the plant lifecycle that involve directly the company and the levels of implementation of areas, software and information flows resulted low significant. Perhaps this lack of significance can be attributed to the fact that the companies of this sector implement areas and flows regardless of the life cycle directly managed (in chapter 8, the correlation was analyzed for the whole sample and was found to be significant).
Limiting the study to the whole sample, it is possible, instead, to observe a strong positive correlation: the highest correlation coefficients are those in correspondence of the design and revamping phase.
Areas and software more influenced by the lifecycle are the DDD and DDR and this is conformed also observing the correlation coefficients of the information flows: the most significant correlations are registered between the design system (DDD) and the design phase (conceptual basic design, detailed design, construction) and between the design system and the MED (note that all these flows are directed from top to bottom; the importance of the feedback information is not understood). Similar considerations can be done for the DDR: have been identified as significant only those flows that come from the MEO and that, after being processed in the redesign system (DDR), are sent to the revamping phase (RVP). Again, all these flows are directed from top to bottom.

Table 84: correlation levels of implementation - manufacturing strategy (whole sample)

		Manufacturing strategy			
		WHOLE SAMPLE			
		Job Shop	Small batch	Large batch	Continuos
Implementation of areas	RPD			-0,25 0,08	
	MED		-0,275 0,053		0,328 0,02
	RCMD				0,281 0,048
	DDD				0,376 0,007

	RPO				
	SIO				
	DDR		-0,237 0,097		0,391 0,005
Implementation of software	MED		-0,243 0,09		0,3 0,034
	DDD		-0,298 0,036		0,4 0,004
	RPO				
	SIO		-0,252 0,078		
	MMO		-0,309 0029		0,253 0,076
	DDR		-0,318 0,025		0,395 0,005
Implementation of infromation flows	MED-DDD			-0,285 0,045	
	MED-RCMD				0,281 0,048
	RCMD-DDD				0,281 0,048
	DDD-CBD		-0,284 0,046		0,431 0,002
	DDD-DD		-0,243 0,089		0,351 0,012
	DDD-C				0,248 0,083
	C-DDD		-0,267 0,061		0,289 0,042
	MED-MEO		-0,258 0,071		0,28 0,049
	DDD-DDR		-0,311 0,028		0,389 0,005
	MMO-MEO				
	MEO-RCMO				
	RCMO-MMO				0,313 0,027
	MMO-RCMO				
	MMO-RPO				
	RPO-MEO				0,281 0,048
	SIO-MMO				
	SIO-MEO			-0,317 0,025	
	MMO-DDR				0,292 0,039
	SIO-MNT/OP	0,433 0,05			
	MNT/OP-SIO			0,271 0,057	
	MMO-MNT/OP		-0,298 0,036		0,338 0,016
	DDR-RVP		-0,326 0,021		0,446 0,001
	RVP-DDR		-0,272 0,056		0,295 0,037

Table 85: correlation levels of implementation - manufacturing strategy (paper sector and chemical/pharmaceutical sector)

		Manufacturing strategy							
		PAPER SECTOR				C/F SECTOR			
		Job Shop	Small batch	Large batch	Conti-nuos	Job Shop	Small batch	Large batch	Conti-nuos
Implementation of areas	RPD								
	MED						-0,382 0,087		0,506 0,019
	RCMD								0,404 0,07
	DDD						-0,403 0,07		0,592 0,005
	RPO								0,404 0,07
	SIO	0,418 0,06					-0,38 0,089		
	DDR			-0,424 0,056			-0,549 0,01		0,747 0
Implementation of software	MED						-0,382 0,087		0,506 0,019
	DDD	0,378 0,092		-0,44 0,046			-0,441 0,045		0,604 0,004
	RPO								0,404 0,07
	SIO						-0,569 0,007		0,527 0,014
	MMO						-0,531 0,013		0,43 0,052
	DDR						-0,428 0,053		0,558 0,009
Implementation of infromation flows	MED-DDD								0,404 0,07
	MED-RCMD								0,404 0,07
	RCMD-DDD								0,404 0,07
	DDD-CBD						-0,416 0,061		0,614 0,003
	DDD-DD						-0,374 0,095		0,479 0,028
	DDD-C								
	C-DDD								
	MED-MEO								
	DDD-DDR						-0,382 0,087		0,506 0,019
	MMO-MEO						-0,373 0,096		0,379 0,09
	MEO-RCMO							-0,398 0,074	0,454 0,039
	RCMO-MMO							-0,398 0,074	0,454 0,039
	MMO-RCMO								0,404 0,07
	MMO-RPO								0,404 0,07
	RPO-MEO								0,404 0,07
	SIO-MMO								0,38 0,09
	SIO-MEO						-0,374 0,095	-0,514 0,017	0,573 0,007
	MMO-DDR								
	SIO-MNT/OP						-0,382 0,087		0,506 0,019

	MNT/OP-SIO								0,38 0,089
	MMO-MNT/OP								0,402 0,071
	DDR-RVP						-0,44 0,046		0,552 0,01
	RVP-DDR								

Analyzing possible correlations between the manufacturing strategy and the levels of implementation of areas, software and flows, it can be observed that the correlation coefficient are all negative in correspondence of small batch production (production of small batches with large variety).

When the production is not of continuous type, the importance of the areas, software and flows decreases, because often the corrective maintenance is the most used maintenance policy, therefore are not required special maintenance tools (this concept is also strengthened by the values found in Table 94 and 95, which show the correlation between the levels of implementation and the corrective maintenance).

Moving from job shop (for this manufacturing strategy were not identified significant correlations, probably because adopted by few companies of the sample) to continuous process (strategy widely adopted by companies of the two industrial sectors), it is observed the increasing of all the levels of implementation.

Making different considerations for the two different industrial sectors, it is possible to note that for the paper companies there are no significant correlations.

Considering that almost all the companies of this sector adopt continuous processes, the lack of significant correlations can be motivated by these factors:

- lack of legislation focused on the quality product (present in the chemical/pharmaceutical sector);
- size of some companies that, even if adopt continuous process, don't have enough resources to implement some maintenance tools;
- lack of knowledge about the maintenance tools and activities.

Different is the situation for the whole sample and the chemical/pharmaceutical sector, where is registered a positive correlation between levels of implementation and continuous processes: areas most affected by the manufacturing strategies are those of the design phase (MED, RCMD and DDD) and of the revamping (DDR).

Similar considerations can be done for the level of implementation of software and information flows: to implement a continuous production strategy, it is needed from the design phase the implementation of maintenance tools necessary to achieve the goal of high availability during the operational stage. This is confirmed by the strong correlation observed with the DDR process: in fact the improvement of the plant (revamping) with the information coming from other areas contributes to ensure high levels of availability to the production system.

Table 86: correlation levels of implementation - technical variety (whole sample)

		Technical variety – WHOLE SAMPLE: Type of production equipment 80% - 20%	Few OEM – Many OEM	Standard equipments – customized equipments	Recurrent failures	Intermittent failures	Unusual failures
Implementation of areas	RPD		-0,288 0,043	0,347 0,013			
	MED				-0,286 0,044		
	RCMD	0,239 0,095					
	MEO			0,241 0,092	-0,499 0		-0,405 0,003
	RCMO	0,386 0,006			-0,326 0,021		
	SIO					0,246 0,085	
	MMO			0,249 0,082			
	DDR			0,329 0,02		0,306 0,031	
Implementation of software	MED				-0,261 0,067		
	MEO				-0,236 0,099		
	RPO	0,244 0,088					
	RCMO	0,251 0,079			-0,238 0,096		
	SIO			0,284 0,046		0,381 0,006	
	MMO			0,38 0,006			
	DDR			0,266 0,062		0,266 0,062	
Implementation of information flows	MED-DDD	0,28 0,049					
	DDD-MED					0,243 0,089	
	MED-RCMD	0,239 0,095					
	RCMD-DDD	0,239 0,095					
	DDD-DD				0,329 0,02	0,256 0,073	
	DDD-C				0,26 0,068		
	C-DDD					0,238 0,095	
	MED-MEO			0,275 0,053	-0,243 0,089		
	DDD-MMO				0,334 0,018		
	DDD-DDR				0,335 0,017	0,278 0,051	
	MEO-MMO				-0,255 0,074		
	MMO-MEO				-0,451 0,001		-0,301 0,034
	MEO-RCMO				-0,267 0,061		
	MMO-RCMO		-0,244				

			0,088				
	MMO-RPO	0,263 0,065					
	RPO-MEO	0,239 0,095					
	SIO-RPO		-0,264 0,064	0,243 0,089			
	MMO-DDR					0,3 0,034	
	SIO-MNT/OP						
	MNT/OP-SIO			0,306 0,031			
	DDR-RVP					0,286 0,044	
	RVP-DDR					0,243 0,089	
	RVP-DDR			0,235 0,1		-0,263 0,065	

Table 87: correlation levels of implementation - technical variety (paper sector and chemical/pharmaceutical sector)

		Technical variety											
		PAPER SECTOR						C/F SECTOR					
		Type of production equipment 80% - 20%	Few OEM – Many OEM	Standard equipments – customized equipments	Recurrent failures	Intermittent failures	Unusual failures	Type of production equipment 80% - 20%	Few OEM – Many OEM	Standard equipments – customized equipments	Recurrent failures	Intermittent failures	Unusual failures
Implementation of areas	RPD												
	MED										-0,447 0,042		0,393 0,078
	RCMD							0,418 0,059					
	MEO						-0,549 0,01			0,533 0,013	-0,549 0,01		
	RCMO		-0,385 0,085					0,475 0,03			-0,478 0,028		
	SIO							0,517 0,016				0,376 0,093	
	MMO							0,568 0,007					0,391 0,079
	DDR			0,397 0,075									
Implementation of software	MED										-0,447 0,042		0,393 0,078
	MEO						-0,447 0,042	0,453 0,039					
	RPO							0,418 0,059					
	RCMO							0,466 0,033			-0,409 0,066		
	SIO				-0,421 0,057							0,509 0,018	
	MMO							0,482 0,027					0,386 0,084
	DDR			0,382 0,087			-0,369 0,1	0,418 0,059					0,381 0,089
Implementation of information	MED-DDD							0,418 0,059					
	DDD-MED												
	MED-RCMD							0,418 0,059					

	RCMD-DDD							0,418 0,059					
	DDD-DD										0,536 0,012		0,436 0,048
	DDD-C									-0,418 0,059	0,453 0,039		0,454 0,039
	C-DDD									-0,418 0,059	0,453 0,039		0,454 0,039
	MED-MEO												0,454 0,039
	DDD-MMO									-0,418 0,059	0,453 0,039		0,454 0,039
	DDD-DDR										0,52 0,016		0,393 0,078
	MEO-MMO										-0,438 0,047		
	MMO-MEO				-0,412 0,063		-0,624 0,003	0,405 0,069		0,495 0,023	-0,609 0,003		
	MEO-RCMO												
	MMO-RCMO								-0,526 0,014				
	MMO-RPO							0,418 0,059					
	RPO-MEO							0,418 0,059					
	SIO-RPO									-0,521 0,015	0,469 0,032		
	MMO-DDR												
	SIO-MNT/OP					-0,47 0,031					0,52 0,016		0,393 0,078
	MNT/OP-SIO												
	DDR-RVP										0,492 0,023	0,381 0,089	0,452 0,04
	RVP-DDR									-0,418 0,059	0,453 0,039		0,454 0,039
	RVP-DDR										-0,478 0,029	-0,37 0,098	

From the analysis of technical variety some consideration emerges, distinguishing the first three elements that are related to the characterization of the equipments (type of production equipments, number of OEM and customization of equipments) from the three that aim to highlight the different types of failure (recurrent, intermittent and unusual failures).
Starting from the study of the results of the elements that characterize the equipments, are observed few correlations for the paper sector (and these correlations present p-value less than 10% but more than 5%). For the whole sample, one of the most significant correlation concerns the RPD area (adopted when there is an high customization of equipments and these are supplied by few OEM), however only two companies of the whole sample implement this area, therefore this correlation cannot be generalized. The presence of customized equipments influences positively the level of adoption of revamping procedures and the presence of software for SIO and MMO areas. No significant considerations have been found for the information flows.
As regards the chemical/pharmaceutical sector, the MEO, MMO, RCMO and SIO areas and software are strongly influenced by the technical variety: greater is the presence of different equipments in the production system and greater is the need of maintenance tools and methodology; the RCM area assumes particular importance in correspondence of an high variety of machines. However, this area is implemented by only 4 pharmaceutical companies, so the results should be considered with caution.
Passing to the analysis of the three coefficient that characterize the technical variety in terms of different type of failures, no significant correlations have been found for the paper

sector, while some interesting result is present in the other industrial sector. From the perspective of the level of implementation of the areas, the correlation coefficients are almost all negative. The presence of negative coefficients was predictable: a greater adoption of the MEO and RCMO areas is required not in those systems where failures are well know and recurrent (and it is required also to reduce the frequency of failures). For what concerns software, the only significant correlation is found for the process control, which has a positive relationship with the frequency of intermittent faults. Finally, in terms of information flows (mainly related to the design and the revamping stages) have been identified positive correlations with the frequency of recurrent and unusual failures during the design phase. Interesting is the positive correlation with the information flows related to the DDR area: greater is the frequency of failures and greater is the need to implement information flows related to the redesign of the plant.

Table 88: correlation levels of implementation - technical complexity (whole sample)

		Technical complexity				
		WHOLE SAMPLE				
		Time needed to identify the failure	Time needed to prepare the intervention	Time needed to repair the failure	Time needed to restart the plant	Machines that implement flexible integrated automation
Implementation of areas	RPD					
	MED			-0,342 0,015		
	RCMD			-0,25 0,079		
	DDD			-0,28 0,049		
	RPO			-0,256 0,073		
	MEO	0,3 0,035				0,267 0,06
	SIO			-0,279 0,05		
	RCMO		-0,249 0,082	-0,366 0,009		
	DDR					
Implementation of software	MED					
	DDD			-0,276 0,052		
	MEO		-0,433 0,002		0,28 0,049	
	RPO			-0,256 0,073		
	SIO					
	RCMO		-0,301 0,033	-0,276 0,053		
	MMO					
	DDR					
Implementation of information flows	MED-DDD					
	MED-RCMD			-0,25 0,079		
	RCMD-DDD			-0,25 0,079		
	DDD-CBD					

	DDD-DD					-0,247 0,084
	DDD-C					-0,33 0,019
	C-DDD					-0,339 0,016
	MED-MEO			-0,254 0,075		
	DDD-DDR					
	MMO-MEO				0,266 0,062	
	MMO-MEO				0,371 0,008	0,241 0,091
	DDD-MMO					-0,423 0,002
	MEO-RCMO			-0,245 0,086		
	RCMO-MMO			-0,261 0,067		
	MMO-RCMO	0,287 0,043				
	MMO-RPO			-0,254 0,075		
	RPO-MEO			-0,25 0,079		
	SIO-MMO					
	SIO-MEO	0,247 0,083				
	MMO-DDR					-0,267 0,061
	SIO-MNT/OP					
	MNT/OP-SIO					
	MMO-MNT/OP					-0,297 0,036
	MNT/OP-MMO					-0,257 0,072
	DDR-RVP					
	RVP-DDR					-0,282 0,047

Table 89: correlation levels of implementation - technical complexity (paper sector and chemical/pharmaceutical sector)

		Technical complexity									
		PAPER SECTOR					C/F SECTOR				
		Time needed to identify the failure	Time needed to prepare the intervention	Time needed to repair the failure	Time needed to restart the plant	Machines that implement flexible integrated automa-tion	Time needed to identify the failure	Time needed to prepare the intervention	Time needed to repair the failure	Time needed to restart the plant	Machines that implement flexible integrated automa-tion
Implementation of areas	RPD										
	MED				0,536 0,012						
	RCMD								-0,411 0,064		
	DDD				0,543 0,011						
	RPO								-0,411 0,064		
	MEO				0,401 0,072		0,465 0,034				0,426 0,054

	SIO										
	RCMO								-0,426 0,054		
	DDR				0,397 0,075						
Implementation of software	MED										
	DDD										
	MEO			-0,405 0,069	0,607 0,004			-0,523 0,015			
	RPO								-0,411 0,064		
	SIO	0,401 0,072			0,486 0,026						
	RCMO							-0,403 0,07	-0,419 0,058		
	MMO										
	DDR				0,371 0,097						
Implementation of information flows	MED-DDD					-0,44 0,046			-0,411 0,064		
	MED-RCMD								-0,411 0,064		
	RCMD-DDD								-0,411 0,064		
	DDD-CBD										
	DDD-DD										-0,385 0,085
	DDD-C										-0,584 0,005
	C-DDD										-0,584 0,005
	MED-MEO										
	DDD-DDR										
	MMO-MEO				0,533 0,013						
	MMO-MEO										
	DDD-MMO										-0,584 0,005
	MEO-RCMO								-0,428 0,053		
	RCMO-MMO								-0,428 0,053		
	MMO-RCMO						0,548 0,01				
	MMO-RPO								-0,411 0,064		
	RPO-MEO								-0,411 0,064		
	SIO-MMO			-0,372 0,097							
	SIO-MEO										
	MMO-DDR										-0,503 0,02
	SIO-MNT/OP										
	MNT/OP-SIO										
	MMO-MNT/OP		0,479 0,028								
	MNT/OP-MMO										
	DDR-RVP										
	RVP-DDR										-0,584 0,005

From the analysis of the technical complexity, the following considerations emerge:

- Areas: from this point of view it has been registered a negative correlation between the level of implementation and the time needed to repair the failure, therefore the adoption of maintenance tools reduces the time of the intervention. In the paper industry the implementation of the RME areas corresponds to an increasing of the time needed to restart the plant. Companies with complex systems require the adoption of adequate maintenance tools (such as the MEO area), but at the same time require a lot of time to restart the plant (because of their complexity).
- Software: in this case it is evident that the adoption of tools such as the MEO and the RCMO reduces the time needed to prepare the intervention and to repair the system, but at the same time increases time needed to restart the plant (this trade-off is strictly related to the technical complexity: high complexity is synonymous of big times for maintenance interventions. These times can be reduced implementing specific tools. Because of the technical complexity, however, restart the plant is not an easy operation and requires a lot of time);
- Information flows: from this point of view, there are few significant correlations. Increasing the complexity of systems, the information flows exchanged during the design and revamping phases decrease. Companies, in fact, are not able to design complex systems, therefore outsource this activities (hence the corresponding flows are not adopted). Some positive correlation is observed for some information flow related to the CCMS (this can be explain, considering that complex systems require an high level of information exchange between critical areas such as the MMO and the MEO).

Table 90: correlation levels of implementation - interdependence

		Interdependence											
		WHOLE SAMPLE				PAPER SECTOR				C/F SECTOR			
		Absence/presence of buffer stocks	Rerouting work is not possible/ possible	Rigid/flexible production flow	Percentage of production process phases that don't stop within the first hour of if a singular machine breakdown occurs	Absence/presence of buffer stocks	Rerouting work is not possible/ possible	Rigid/flexible production flow	Percentage of production process phases that don't stop within the first hour of if a singular machine breakdown occurs	Absence/presence of buffer stocks	Rerouting work is not possible/ possible	Rigid/flexible production flow	Percentage of production process phases that don't stop within the first hour of if a singular machine breakdown occurs
Implementation of areas	RPD												
	MED		-0,275 0,054		-0,247 0,084								-0,37 0,099
	RCMD												
	DDD			-0,267 0,061					-0,379 0,09				
	RPO												
	MEO	-0,265 0,063	-0,316 0,025					-0,457 0,037					
	SIO			-0,373 0,008				-0,457 0,037					
	RCMO					0,515 0,017	0,787 0	0,462 0,035					
	MMO		-0,271 0,057								-0,501 0,021		
	DDR												

Implementation of software	MED												-0,37 0,099
	DDD												
	RPO												
	SIO			-0,321 0,023				-0,428 0,053					
	MEO		-0,328 0,02						-0,435 0,049		-0,406 0,068		
	MMO										-0,485 0,026		
	DDR								-0,376 0,093				
Implementation of information flows	MED-DDD												
	MED-RCMD												
	RCMD-DDD												
	DDD-CBD												
	DDD-DD	-0,29 0,041											
	DDD-C	-0,283 0,047		-0,254 0,075									
	C-DDD												
	MED-MEO				-0,267 0,061								-0,427 0,053
	DDD-DDR												
	MMO-MEO		-0,325 0,021										
	MEO-RCMO												
	RCMO-MMO												
	MMO-RCMO												
	MMO-RPO												
	RPO-MEO												
	SIO-RPO		0,282 0,048										
	SIO-MMO												
	SIO-MEO												
	MMO-DDR												
	SIO-MNT/OP												
	MNT/OP-SIO											-0,422 0,057	
	MMO-MNT/OP												
	MNT/OP-MMO		-0,283 0,046					0,406 0,068			-0,381 0,088		
	DDR-RVP	-0,273 0,055		-0,239 0,094									
	RVP-DDR												

From the perspective of the interdependence, few significant correlations were found; concerning the level of implementation of the areas, in the design phase there aren't important results, while in the operational phase negative correlations with the system flexibility are identified. More the productive system is interdependent/rigid and higher is the level of implementation of areas such as MEO, SIO and MMO (this is normal because a rigid process requires maintenance activities that are not of corrective type, but of preventive and predictive type: to apply these policies are needed maintenance tools such as the Maintenance Engineering, the Process Control and the CMMS). Same results can be found in the analysis of the implementation level of software: greater is the rigidity of the production system and greater is the need to implement not only the areas above described, but also the related software. Finally, concerning the information flows, for paper and chemical/pharmaceutical sectors have not been found significant correlations, while analyzing the entire sample some negative correlation are present (only exception is the SIO-RPO flow, but considering that only three companies implement the RPO area, this result is not so relevant). This result was expected, in fact, greater is the rigidity of the production process and higher is the need of information flows that allow to manage the plant: it is observed an increasing implementation of the design phase flows (to consider from the design phase all the mechanisms necessary to adopt advanced maintenance tools), of the flows necessary to collect and process all the information coming from the field and of the flows needed to activate the process of plant improvement (DDR-RVP).

Table 91: correlation levels of implementation - equipments average age

		Equipments average age		
		WHOLE SAMPLE	PAPER SECTOR	C/F SECTOR
Implementaion of areas	RPD			
	MED			
	RCMD			
	DDD			0,41 0,065
	RPO			
	RCMO	-0,281 0,048		
	SIO			
	DDR			
Implementaion of software	MED			
	DDD			0,425 0,055
	RPO			
	RCMO	-0,266 0,062		
	SIO			
	MMO			
	DDR			
Implementaion of information flows	MED-DDD			
	MED-RCMD			
	RCMD-DDD			
	DDD-CBD			0,512 0,018
	DDD-DD			0,644 0,002

	DDD-C			0,419 0,059
	C-DDD			0,419 0,059
	MED-MEO			
	DDD-DDR	0,326 0,021		0,671 0,001
	MMO-MEO			
	MEO-MMO	-0,308 0,03		
	MEO-RCMO			
	RCMO-MMO			
	MMO-RCMO			
	MMO-RPO			
	RPO-MEO			
	SIO-MMO			
	SIO-MEO			0,405 0,069
	MMO-DDR			
	SIO-MNT/OP			0,671 0,001
	MNT/OP-SIO			
	MMO-MNT/OP			
	DDR-RVP			0,611 0,003
	RVP-DDR			0,419 0,059

Finally, concerning the study of the correlation between the equipments average age and the level of implementation of areas, software and information flows, can be drawn the following considerations: for the areas, the only significant correlation found is related to the difficulty of a RCM implementation during the operational phase if the plant age is high (this is quite comprehensible, because it is difficult to implement in old equipments modern approach that requires a constant monitoring). For software the same considerations can be carried out, but only considering a significance level of 10%.

9.3 *Correlations between the maintenance variables and the implementation variables*

The variables considered to investigate these correlations have been:

- *Quantitative maintenance variables*:
  - Maintenance strategy;
  - CMMS activities adopted;
  - Human resource.
- *Quantitative implementation variables*:
  - Level of implementation of the reference model areas;
  - Level of implementation of the related software;
  - Level of implementation of the related information flows.

Table 92: correlation maintenance strategy 1/2 - levels of implementation of areas and software

			Implementation of areas									Implementation of software								
			MED	RCMD	DDD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO		MMO	DDR
Maintenance strategy	WHOLE SAMPLE	N° graduated engineers		0,2 0,097		0,299 0,039		0,263 0,07		0,394 0,006				0,362 0,011	0,394 0,006	0,377 0,008			0,252 0,084	0,248 0,089
		N° supervisors	0,49 0	0,7 0	0,54 0	0,4 0		0,61 0	0,423 0,003	0,391 0,006	0,348 0,015	0,551 0	0,582 0	0,443 0,002	0,772 0	0,624 0			0,319 0,027	0,543 0
		N° maintenance technicians	0,41 0	0,489 0	0,3 0	0,44 0,002		0,385 0,007	0,54 0	0,412 0,004	0,368 0,01	0,294 0,043	0,303 0,036	0,543 0	0,594 0	0,659 0			0,344 0,017	0,467 0,001
	PAPER SECTOR	N° graduated engineers				0,417 0,06	0,45 0,03			0,587 0,005				0,541 0,011	0,672 0,001	0,672 0,001			0,39 0,081	0,659 0,001
		N° supervisors				0,513 0,017	0,57 0,01			0,422 0,057				0,707 0	0,687 0,001	0,687 0,001	0,536 0,012			0,555 0,009
		N° maintenance technicians	0,44 0,04			0,467 0,033								0,616 0,003	0,643 0,002	0,643 0,002				0,57 0,007
	C/F SECTOR	N° graduated engineers		0,4 0,072		0,43 0,052		0,4 0,072	0,41 0,065						0,4 0,072	0,376 0,093				
		N° supervisors	0,63 0,01	0,819 0	0,73 0	0,542 0,011		0,819 0	0,508 0,019		0,438 0,047	0,639 0,002	0,725 0		0,819 0	0,621 0,003				0,53 0,013
		N° maintenance technicians	0,41 0,06	0,707 0		0,586 0,005		0,707 0	0,83 0		0,413 0,063	0,413 0,062		0,531 0,013	0,707 0	0,803 0				

Table 93: correlation maintenance strategy 1/2 - levels of implementation of information flows

			Implementation of information flows																
			DDD-CBD	MED -DDD	MED-RCMD	RCMD-DDD	DDD-CBD	DDD-DDR	MEO-MMO	MMO-MEO	MEO-RCMO	RCMO-MMO	MMO-RPO	RPO-MEO	SIO-MEO	SIO-MNT/OP	MMO-MNT/OP	DDD-C	MEO-DDR
Maintenance strategy	WJOLE SAMPLE	N° graduated engineers			0,24 0,09	0,242 0,097			0,536 0	0,535 0	0,605 0	0,346 0,016	0,242 0,097	0,242 0,097	0,262 0,072			0,314 0,03	
		N° supervisors		0,328 0,023	0,70 0	0,704 0	0,47 0,00	0,25 0,08	0,429 0,002	0,467 0,001	0,629 0	0,544 0	0,704 0	0,704 0		0,258 0,077		0,41 0,004	
		N° maintenance technicians			0,48 0	0,489 0	0,27 0,06		0,579 0	0,459 0,001	0,681 0	0,537 0	0,489 0	0,489 0			0,35 0,015	0,391 0,006	
	PAPER SECTOR	N° graduated engineers							0,672 0,001	0,513 0,017	0,672 0,001					0,47 0,032			
		N° supervisors							0,687 0,001	0,462 0,035	0,687 0,001								
		N° maintenance technicians							0,643 0,002	0,403 0,07	0,643 0,002								
	C/F SECTOR	N° graduated engineers		0,4 0,072	0,4 0,07	0,4 0,072			0,667 0,001	0,597 0,004	0,57 0,007	0,57 0,007	0,4 0,072	0,4 0,072			0,411 0,064	-0,388 0,083	
		N° supervisors		0,819 0	0,81 0	0,819 0	0,59 0,00			0,484 0,026	0,605 0,004	0,605 0,004	0,819 0	0,819 0					0,485 0,026
		N° maintenance technicians		0,707 0	0,70 0	0,707 0			0,612 0,003	0,527 0,014	0,75 0	0,75 0	0,707 0	0,707 0			0,564 0,008		0,586 0,005

Starting from the analysis of the maintenance strategy (in terms of maintenance workforce), it is evident, especially for the whole sample, the positive strong correlation between the number of graduated engineers, supervisors and maintenance technicians and the level of implementation of areas and software. Activities that require qualified personnel, such as

the RCMO, RCMD and RPO, are those most influenced by the presence of maintenance workforce. Same considerations can be carried out for the information flows: in this case a greater correlation is observed with the number of maintenance technicians and supervisors. For every level of implementation, in the paper sector a lower number of significant correlations have been registered. Probably this is due to the fact that companies of this industrial sector adopt the areas at a lower level of implementation.
In general, anomalous behaviors were not registered and almost all the correlations are positive: it was expected a more significant correlation with the number of engineers, especially for those areas where is required an high level of knowledge. However, this may be explained by the fact that in general the number of engineers is low (often one, two or three engineers); the more relevant element is the number of maintenance technicians and supervisors. The graduated engineers are responsible for the coordination of the maintenance activities and for the application of certain techniques; maintenance technicians and supervisors are those who "concretize" the decisions taken by the graduated engineers.

Table 94: correlation maintenance strategy 2/2 - levels of implementation of areas and software

		Implementation of areas									Implementation of software							
Maintenance strategy		RPD	MED	DDD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	Corrective maintenance		-0,24 0,09		-0,32 0,02		-0,252 0,08				-0,311 0,03							
	Preventive maintenance	0,243 0,093											0,32 0,025			0,24 0,08		
	Predictive maintenance		0,473 0,001			0,258 0,074					0,324 0,023							
PAPER SECTOR	Corrective maintenance			-0,463 0,035	-0,513 0,017	-0,45 0,041							-0,418 0,059			-0,588 0,005		
	Preventive maintenance											0,479 0,028						
	Predictive maintenance		0,466 0,033	0,546 0,01	0,386 0,084								0,556 0,009			0,633 0,002		
C/F SECTOR	Corrective maintenance		-0,495 0,022		-0,418 0,059						-0,495 0,022							
	Preventive maintenance																	
	Predictive maintenance		0,497 0,022						0,453 0,039		0,497 0,022						0,43 0,052	

Table 95: correlation maintenance strategy 2/2 - levels of implementation of information flows

Maintenance strategy		Implemetation of information flows															
		DDD-DD	MED -MEO	RCMD-DDD	DDD-CBD	DDD-DDR	MEO-MMO	MMO-MEO	MEO-RCMO	RCMO-MMO	SIO-MNT/OP	DDD-C	MNT/OP-SIO	SIO-MMO	MNT/OP-MMO	MMO-MNT/OP	DDR-RVP
WHOLE SAMPLE	Corrective maintenance	0,315 0,028				0,254 0,079		-0,4 0,004								0,244 0,091	0,302 0,035
	Preventive maintenance					-0,252 0,08						0,304 0,034					
	Predictive maintenance							0,368 0,009									
PAPER SECTOR	Corrective maintenance							-0,41 0,065					-0,512 0,018	-0,372 0,097	0,421 0,057	0,41 0,065	
	Preventive maintenance														-0,399 0,074	-0,471 0,031	
	Predictive maintenance							0,395 0,077					0,438 0,047		-0,494 0,023	-0,391 0,079	
C/F SECTOR	Corrective maintenance	-0,38 0,08						-0,517 0,016									
	Preventive maintenance					-0,393 0,078											-0,453 0,039
	Predictive maintenance		0,537 0,012					0,43 0,052			-0,393 0,078						

In the tables showed above, are examined the correlations between the levels of implementation of areas, software and flows and the level of adoption of the three different types of maintenance policies: corrective, preventive and predictive. Compared to the case studied before, the significant correlations were found to be few in number and often negative, especially in the case of corrective maintenance. The fact that the level of implementation is inversely proportional to the use of corrective maintenance is an expected result because the

companies that adopt this maintenance strategy don't require many particular tools to support the maintenance activity (for example, there isn't the need to collect data to determine when perform interventions of preventive maintenance).
Positive correlations were observed, (although often not very significant due to high p-value), between the levels of implementation and the preventative maintenance. But the most significant results have been obtained for the predictive maintenance (positive correlations). In both the industrial sectors the MED are is the most correlated to the predictive maintenance: in fact for a correct and complete adoption of this maintenance policy, it must be taken in consideration from the design stage.
Concerning the information flows, the results were conflicting: the correlations registered for the corrective and preventive maintenance are almost always negative; in terms of predictive maintenance, especially as regards the chemical/pharmaceutical sector, the level of implementation of some flows (specifically MMO-MEO, MED-MEO and MNT/OP-SIO) is positively correlated. Two of these flows are directed to the maintenance engineering area, fundamental for this maintenance policy. For the reverse flows the correlations are negative or not significant. This behavior can be explained with the considerations emerged in the Chapter 6 for what concerns the level of knowledge: the lack of awareness of the importance to connect the different areas of the maintenance process is also found in companies that adopt predictive maintenance.

Table 96: correlation CMMS activities (1/4) - levels of implementation of areas and software

			Implementation of areas									Implementation of software							
			RPD	MED	DDD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
CMMS activities	WHOLE SAMPLE	Planning and scheduling of work orders								0,41 0,003			0,325 0,021	0,248 0,083				0,535 0	0,252 0,077
		Planning of maintenance activities (preventive and predictive)							0,283 0,046	0,333 0,018						0,254 0,075		0,415 0,003	
		Data recording of works performed		0,278 0,05				0,236 0,099	0,305 0,031	0,344 0,014	0,295 0,037	0,246 0,085					0,236 0,099	0,463 0,001	
	PAPER SECTOR	Planning and scheduling of work orders																0,374 0,095	

	Planning of maintenance activities (preventive and predictive)										0,442 0,045					0,448 0,042	
	Data recording of works performed															0,441 0,046	
C/F SECTOR	Planning and scheduling of work orders								0,5 0,021				0,429 0,052			0,401 0,072	0,704 0	
C/F SECTOR	Planning of maintenance activities (preventive and predictive)																0,52 0,016	
C/F SECTOR	Data recording of works performed							0,371 0,098	0,38 0,089	0,51 0,018							0,565 0,008	

Table 97: correlation CMMS activities (1/4) - level of implementation of information flows

CMMS activities		Implementation of information flows															
		DDD-DD	MED -MEO	RCMD-DDD	DDD-CBD	DDD-DDR	MEO-MMO	MMO-MEO	MMO-RCMO	RCMO-MMO	SIO-MNT/OP	SIO-MEO	MNT/OP-SIO	SIO-MMO	MNT/OP-MMO	MMO-MNT/OP	MEO-DDR
WHOLE SAMPLE	Planning and scheduling of work orders						0,297 0,036	0,308 0,029			0,272 0,056	-0,31 0,029			0,244 0,087		
WHOLE SAMPLE	Planning of maintenance activities (preventive and predictive)							0,34 0,016				-0,337 0,017					0,246 0,085
WHOLE SAMPLE	Data recording of works performed							0,416 0,003		0,241 0,092	0,251 0,079	-0,265 0,063	0,304 0,032	0,263 0,065	0,236 0,099	0,248 0,082	0,256 0,073

	C/F SECTOR			PAPER SECTOR		
	Data recording of works per-formed	Planning of maintenance activities (preventive and	Planning and scheduling of work orders	Data recording of works performed	Planning of maintenance activities (preventive and	Planning and scheduling of work orders
		-0,371 0,098				
	0,566 0,008	0,377 0,092				
	0,603 0,004	0,495 0,023	0,399 0,073	0,389 0,081		
			-0,389 0,081			
		-0,371 0,098		0,405 0,068		
				-0,583 0,006	-0,377 0,092	-0,452 0,04
				0,402 0,071		0,374 0,094
				0,407 0,067		

The analysis of the correlations between the maintenance planning and control system (CMMS) and the levels of implementation has been split up into 4 parts. The first part focuses on the correlations with the "*Planning and scheduling of work orders*", "*Planning of maintenance activities (preventive and predictive)*" and "*Data recording of works performed*" modules.

From the observation of the tables above, the following considerations emerge:

- the most significant correlations are present for the whole sample and for the chemical/pharmaceutical sector, but are few in number;
- the correlations with the levels of implementation of areas and software are all positive, while those with the information flows are prevalent negative.

Analyzing the whole sample, the correlation between the "*Data recording of works performed*" and the level of adoption of areas and software is the predominant; the most significant areas are the RCMO and the MMO, both belonging to the operational phase. For these two activities was found a positive and significant correlation also with the "*Planning of maintenance activities (preventive and predictive)*". This last correlation was an expect result, because of the nature of the RCMO and MMO activities (they define the maintenance policies and the maintenance plan, managed by the CMMS). From the perspective of the software implementation, the most interesting correlation concerns the MMO and it is positive and significant both in the whole sample and in the paper and chemical/pharmaceutical sectors. This result highlights once again how the considerations above expressed for the MMO. Another confirmation of this is provided by the analysis of the information flows: the few positive and significant correlations are registered for those flows that involve the MMO area. Curious case is the flow SIO-MEO: excluding the chemical/pharmaceutical sector where the SIO area is not widely implemented, for the whole sample and especially for the paper sector, are always observed negative correlations: this probably can be explained by the fact that companies with a CMMS mainly use the links SIO-MMO and MMO-MEO, rather than the flow SIO-MEO.

Table 98: correlation CMMS activities (2/4) - levels of implementation of areas and software

			Implementation of areas									Implementation of software							
			RPD	MED	DDD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
CMMS activities	WHOLE SAMPLE	Spare parts management (inventory)					0,34 0,01	0,245 0,087	0,317 0,025	0,528 0	0,39 0,005		0,35 0,013	0,318 0,025			0,409 0,003	0,616	0,345 0,014
		Maintenance workforce management		0,296 0,037	0,383 0,006		0,37 0,008		0,27 0,058	0,314 0,027	0,401 0,004		0,489 0				0,303 0,032	0,394 0,005	0,423 0,002
		Spare parts management (purchasing)					0,27 0,05			0,462 0,001	0,378 0,007		0,303 0,033				0,378 0,007	0,573 0	0,324 0,022
	PAPER SECTOR	Spare parts management (inventory)			0,432 0,051								0,568 0,007						
		Maintenance workforce management				0,396 0,076					0,401 0,072		0,446 0,043					0,386 0,084	
		Spare parts management (purchasing)								0,484 0,026	0,595 0,004		0,591 0,005					0,587 0,005	
	C/F SECTOR	Spare parts management (inventory)				0,372 0,097	0,501 0,021			0,557 0,009	0,438 0,047				0,441 0,045		0,599 0,004	0,718 0	

Maintenance workforce management			0,554 0,009		0,546 0,01			0,467 0,033	0,461 0,035		0,566 0,008				0,423 0,056	0,462 0,035	0,523 0,015
Spare parts management (purchasing)					0,448 0,041									-0,372 0,097	0,595 0,004	0,484 0,026	

Table 99: correlation CMMS activities (2/4) - level of implementation of information flows

CMMS activities			Implementation of information flows																
			DDD-DD	MED -DDD	DDD-CBD	DDD-C	C-DDD	DDD-MEO	DDD-MMO	MEO-MMO	MMO-MEO	SIO-MMO	MMO-DDR	SIO-MNT/OP	MNT/OP-SIO	MEO-DDR	MMO-MNT/OP	DDR-RVP	RVP-DDR
	WHOLE SAMPLE	Spare parts management (inventory)					0,262 0,067			0,329 0,02	0,405 0,004	0,326 0,021		0,478 0	0,424 0,002		0,371 0,008	0,313 0,027	0,267 0,061
		Maintenance workforce management	0,408 0,003	0,293 0,039	0,347 0,014	0,306 0,031	0,403 0,004	0,273 0,055	0,288 0,042		0,237 0,098	0,406 0,003	0,394 0,005	0,572 0	0,325 0,021		0,375 0,007	0,452 0,001	0,412 0,003
		Spare parts management (purchasing)	0,285 0,045				0,297 0,036				0,238 0,095		0,272 0,056	0,364 0,009	0,344 0,015		0,255 0,074	0,376 0,007	0,303 0,032
	PAPER SECTOR	Spare parts management (inventory)		0,541 0,011							0,514 0,017	0,415 0,062		0,573 0,007	0,414 0,062	0,477 0,029			
		Maintenance workforce management									0,42 0,058			0,521 0,015	0,43 0,052	0,549 0,01			
		Spare parts management (purchasing)														0,57 0,007			
	C/F SECTOR	Spare parts management (inventory)								0,475 0,03	0,565 0,008	0,418 0,06			0,471 0,031		0,419 0,059		
		Maintenance workforce management	0,684 0,001		0,598 0,004	0,481 0,027	0,481 0,027		0,481 0,027			0,67 0,001		0,699 0	0,479 0,028		0,678 0,001	0,632 0,002	0,481 0,027

	Spare parts management (purchasing)													0,436 0,048			0,41 0,065	

Analyzing the correlations between the levels of implementation and the "*Spare parts management (inventory)*", "*Spare parts management (purchasing)*" and "*Maintenance workforce management*" activities, more interesting results have been found.
In particular, the "*Maintenance workforce management*" is the activity that presents the highest number of correlations (especially for the whole sample and the chemical/pharmaceutical sector). Companies that implement this module are often large enterprises with many employees (see the positive correlation with the workforce in the table 70): this means an higher availability of qualified maintenance personnel and therefore an higher availability of knowledge (and this is an important catalyst for the implementation of areas, software and information flows as discussed before for the table 92 and 93).
Also the "*Spare parts management (inventory)*" activity presents some interesting correlation, especially with the information flows: in both the industrial sectors is evident the importance of the exchange of information for a correct management of the spare parts (in particular between MMO, MEO and MNT/OP).
From the analysis of the results, it is evident that the most interesting correlations concern areas, software and flows of the operational stage. This is obvious because the three CMMS modules considered are implemented to manage typical activities of the operational stage (spare parts and workforce).

Table 100: correlation CMMS activities (3/4) - levels of implementation of areas and software

			Implementation of areas									Implementation of software							
			RPD	MED	DDD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
CMMS activities	WHOLE SAMPLE	Maintenance costs budgeting and reporting			0,34 0,016								0,452 0,001					0,258 0,071	0,321 0,023
		Data reporting of maintenance works performed		0,374 0,008					0,279 0,05	0,405 0,004	0,377 0,007	0,295 0,038	0,271 0,057	0,243 0,089				0,416 0,003	0,283 0,046
		Data base for availability/reliability analysis			0,273 0,055	0,354 0,012		0,301 0,034	0,341 0,015	0,413 0,003	0,318 0,025		0,274 0,054	0,371 0,008	0,301 0,034	0,348 0,013		0,458 0,001	0,368 0,008
	PAPER SECTOR	Maintenance costs budgeting and reporting			0,395 0,076								0,48 0,028						

	Data reporting of maintenance works performed		0,499 0,021														0,437 0,047	
	Data base for availability/reliability analysis		0,397 0,075						0,499 0,021								0,567 0,007	
C/F SECTOR	Maintenance costs budgeting and reporting											0,427 0,054						
	Data reporting of maintenance works performed								0,452 0,04	0,437 0,047							0,477 0,029	
	Data base for availability/reliability analysis				0,477 0,029			0,38 0,089					0,534 0,013		0,435 0,049		0,505 0,02	

Table 101: correlation CMMS activities (3/4) - level of implementation of information flows

CMMS activities		Implementation of information flows																
		DDD-DD	MED -DDD	DDD-DDR	DDD-C	C-DDD	SIO-MEO	DDD-MMO	MEO-MMO	MMO-MEO	SIO-MMO	MMO-DDR	SIO-MNT/OP	MNT/OP-MMO	MEO-DDR	MMO-MNT/OP	DDR-RVP	RVP-DDR
WHOLE SAMPLE	Maintenance costs budgeting and reporting	0,266 0,062	0,283 0,047	0,335 0,018		0,287 0,043		0,248 0,083		0,251 0,078	0,267 0,061	0,253 0,077	0,414 0,003				0,355 0,011	0,293 0,039
	Data reporting of maintenance works performed		0,301 0,034				-0,307 0,03		0,241 0,092	0,439 0,001				0,267 0,061	0,296 0,037			
	Data base for availability/reliability analysis	0,274 0,054		0,316 0,025	0,241 0,091	0,347 0,014				0,395 0,005	0,313 0,027	0,25 0,079	0,357 0,011	0,293 0,039	0,342 0,015	0,355 0,012	0,312 0,027	0,354 0,012

	C/F SECTOR			PAPER SECTOR		
	Data base for availability/reliability analysis	Data reporting of maintenance works performed	Maintenance costs budgeting and reporting	Data base for availability/reliability analysis	Data reporting of maintenance works performed	Maintenance costs budgeting and reporting
	0,397 0,075		0,393 0,078			
	0,377 0,092		0,402 0,071			
					-0,477 0,029	-0,491 0,024
		0,373 0,095				
	0,395 0,077	0,467 0,033		0,508 0,019	0,455 0,038	0,396 0,075
	0,4 0,072		0,379 0,09			
	0,377 0,092		0,402 0,071			
	0,51 0,018					
	0,435 0,049		0,462 0,035			
	0,457 0,037					

In the two tables above are analyzed the correlations between the levels of implementation and the "*Maintenance costs budgeting and reporting*", "*Data reporting of maintenance works performed*" and "*Data base for availability/reliability analysis*" activities.
In this case interesting correlations have been found for the whole sample. The "*Maintenance costs budgeting and reporting*" module is correlated with the DDD and DDR areas and also with the related flow DDD-DDR. This means that company that encompass a larger part of the plant lifecycle pay more attention to control their maintenance costs.
Concerning the "*Data reporting of maintenance works performed*" activity, correlations were found with the implementation of RCMO, MMO and DDR areas (and software): reports on maintenance work performed are recorded into the CMMS and such information are used by the RCMO and DDR areas to define new maintenance policies or new improvements/updates of the system (revamping).
The most important correlations are observed for those companies that use the CMMS as *Data base for availability/reliability analysis*". In fact, companies that implement many areas are more sensitive to collect data for reliability evaluations to translate into system improvements (revamping). This is evidenced also by the strong correlation with the information flows: data and information collected must be transferred from one area to another.

In analogy with the behavior observed in the tables 96, 97 and 101, also here the SIO-MEO flow loses importance (negative correlation): companies that implement the CMMS don't adopt the direct flow between the process control area (SIO) and the engineering maintenance area (MEO), but adopt a combination of flows that pass through the CMMS (combination of SIO-MMO and MMO-MEO flows).

Table 102: correlation CMMS activities (4/4) - levels of implementation of areas and software

CMMS activities		Implementation of areas									Implementation of software							
		RPD	MED	DDD	RPO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	Data base for the optimization of the maintenance policies		0,317 0,025	0,318 0,025			0,337 0,017	0,421 0,002	0,241 0,092	0,319 0,024		0,345 0,014		0,266 0,062	0,325 0,021		0,257 0,072	0,303 0,033
WHOLE SAMPLE	Data base for the redesign of components or equipments			0,267 0,061		0,329 0,02	0,368 0,009	0,399 0,004	0,387 0,005	0,38 0,006	0,24 0,094	0,274 0,054	0,295 0,038		0,304 0,032	0,239 0,095	0,42 0,002	0,398 0,004
PAPER SECTOR	Data base for the optimization of the maintenance policies																	
PAPER SECTOR	Data base for the redesign of components or equipments				0,482 0,027						0,482 0,027							
C/F SECTOR	Data base for the optimization of the maintenance policies							0,438 0,047		0,5 0,021					0,44 0,046			
C/F SECTOR	Data base for the redesign of components or equipments							0,419 0,059	0,434 0,049	0,485 0,026					0,412 0,064		0,487 0,025	

Table 103: correlation CMMS activities (4/4) - level of implementation of information flows

CMMS activities		Implementation of information flows: DDD-DD	MED -DDD	DDD-DDR	DDD-C	C-DDD	SIO-MEO	DDD-MMO	MEO-MMO	MMO-MEO	SIO-MMO	MMO-DDR	SIO-MNT/OP	MNT/OP-MMO	MEO-DDR	MMO-MNT/OP	DDR-RVP	RVP-DDR
WHOLE SAMPLE	Data base for the optimization of the maintenance policies	0,256 0,072		0,261 0,067	0,277 0,052	0,381 0,006		0,272 0,056		0,285 0,045	0,254 0,075	0,258 0,071	0,345 0,014	0,339 0,016	0,279 0,05	0,409 0,003	0,283 0,046	0,389 0,005
	Data base for the redesign of components or equipments	0,322 0,023		0,295 0,037	0,398 0,004	0,501 0	-0,274 0,054	0,427 0,002		0,396 0,004	0,424 0,002	0,437 0,002	0,436 0,002	0,28 0,049	0,367 0,009	0,376 0,007	0,4 0,004	0,487 0
PAPER SECTOR	Data base for the optimization of the maintenance policies						-0,452 0,04						0,394 0,077	0,471 0,031		0,394 0,077		
	Data base for the redesign of components or equipments									0,58 0,006	0,562 0,008		0,7 0		0,547 0,01			
C/F SECTOR	Data base for the optimization of the maintenance policies									0,392 0,079						0,504 0,02		
	Data base for the redesign of components or equipments	0,395 0,077			0,56 0,008	0,56 0,008		0,56 0,008			0,409 0,065	0,433 0,05				0,522 0,015	0,477 0,029	0,56 0,008

To conclude the analysis of the maintenance planning and control system, the two tables above show the correlations between the levels of implementation and the "*Data base for the optimization of the maintenance policies*" and the "*Data base for the redesign of components or equipments*" modules.

Also in this case the most interesting correlations have been found for the whole sample. It was expected the correlation between these two modules and some areas like RPO, RCMO, MMO and DDR: these areas, in fact, are implemented to optimize the maintenance policies and to redesign the equipments. These correlations were also identified for the levels of implementation of software and information flows.

Limiting the study to the first of the two activities considered, the difference between the whole sample and the two industrial sectors are significant, especially for the paper sector (where the level of adoption of these CMMS activities is limited).

Instead, for what concerns the second module, these differences are reduced, especially for the chemical/pharmaceutical sector (where all the correlations are positive).

Table 104: correlation human resource 1/2 - levels of implementation of areas and software

Human resource			Implementation of areas									Implementation of software							
			RPD	MED	RCMD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	Training on issues of maintenance	graduated engineers													0,276 0,053			0,339 0,016	
		supervisors		0,24 0,094	0,445 0,001	0,338 0,016		0,387 0,005	0,373 0,008		0,285 0,045	0,249 0,082			0,488 0	0,373 0,008			0,358 0,011
		maintenance technicians			0,407 0,003			0,378 0,007	0,322 0,023	0,328 0,02	0,293 0,039	0,294 0,038			0,505 0	0,418 0,003		0,271 0,057	0,371 0,008
		production operators		0,241 0,092	0,418 0,003			0,358 0,011	0,364 0,009	0,254 0,075		0,306 0,031			0,391 0,005	0,342 0,015			0,319 0,024
PAPER SECTOR	Training on issues of maintenance	graduated engineers								0,376 0,093	0,465 0,034								
		supervisors					0,432 0,051			0,393 0,078	0,435 0,049								
		maintenance technicians					0,483 0,027				0,506 0,019								
		production operators							0,369 0,1										
C/F SECTOR	Training on issues of maintenance	graduated engineers				0,483 0,026													
		supervisors			0,584 0,005	0,509 0,018		0,584 0,005	0,373 0,096						0,584 0,005	0,414 0,062			
		maintenance technicians		0,423 0,056	0,551 0,01			0,551 0,01				0,423 0,056			0,551 0,01	0,439 0,046			0,378 0,091
		production operators		0,423 0,056	0,551 0,01			0,551 0,01				0,423 0,056			0,551 0,01	0,439 0,046			0,378 0,091

Table 105: correlation human resource 1/2 - level of implementation of information flows

Human resource			Implementation of information flows																
			DDD-DD	MED -DDD	MED -RCMD	RCMD-DDD	MMO-RPO	MEO-RCMO	RCMO-MMO	MEO-MMO	MMO-MEO	RPO-MEO	SIO-RPO	SIO-MNT/OP	MNT/OP-SIO	MEO-DDR	MNT/OP-MMO	MEO-DDR	RVP-DDR
WHOLE SAMPLE	Training on issues of maintenance	graduated engineers					0,282 0,048			0,251 0,079			0,442 0,001		0,249 0,082	0,386 0,006			
		supervisors		0,252 0,077	0,445 0,001	0,445 0,001	0,489 0	0,342 0,015	0,378 0,007	0,282 0,047	0,317 0,025	0,445 0,001				0,442 0,001			
		maintenance technicians			0,407 0,003	0,407 0,003	0,498 0	0,3 0,034	0,336 0,017			0,407 0,003				0,432 0,002			
		production operators			0,418 0,003	0,418 0,003	0,458 0,001		0,349 0,013			0,418 0,003		-0,372 0,008				0,457 0,001	
PAPER SECTOR	Training on issues of maintenance	graduated engineers															0,393 0,078	0,499 0,021	
		supervisors									0,425 0,055				-0,381 0,088				
		maintenance technicians									0,447 0,042								
		production operators												-0,391 0,079					
CH	Training on issues of	graduated engineers								0,398 0,074	0,471 0,031							0,478 0,028	

			supervisors		0,584 0,005	0,584 0,005	0,584 0,005	0,584 0,005	0,494 0,023	0,494 0,023		0,413 0,063	0,584 0,005						0,714 0	
			maintenance technicians		0,551 0,01	0,551 0,01	0,551 0,01	0,551 0,01	0,424 0,055	0,424 0,055			0,551 0,01						0,67 0,001	
			production operators			0,551 0,01	0,551 0,01	0,551 0,01	0,551 0,01	0,424 0,055			0,551 0,01						0,67 0,001	

Strong correlations (especially for the whole sample and the chemical/pharmaceutical sector) are observed between the levels of implementation of areas, software and flows and the time spent each year in training of supervisors, technicians and operators on issues of maintenance (the correlation is less evident for the engineers). This result is quite obvious: to implement and manage correctly certain elements of the maintenance process, the personnel must be trained. The graduated engineers have a cultural baggage that require a lower time of training. As expected, activities that require more training are the RCM and RPO areas (the two most advanced techniques considered in this work).

Table 106: correlation human resource 2/2 - levels of implementation of areas and software

					Implementation of areas								Implementation of software						
				RPD	MED	RCMD	MEO	SIO	RPO	RCMO	MMO	DDR	MED	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
Human resource	WHOLE SAMPLE	Degree of involvement of production operators in	routine maintenance interventions																	
			resettlement of simple breakdowns							0,296 0,037				0,257 0,072						
			works of preventive maintenance								-0,273 0,055									
			works of predictive maintenance																	
	PAPER SECTOR	Degree of involvement of production operators in	routine maintenance interventions				-0,533 0,013													
			resettlement of simple breakdowns				-0,456 0,038			0,405 0,069										
			works of preventive maintenance						-0,571 0,007		0,514 0,017									
			works of predictive maintenance			0,508 0,019														
	C/F SECTOR	Degree of involvement of production operators in	routine maintenance interventions			0,376 0,093			0,376 0,093							0,376 0,093				
			resettlement of simple breakdowns					0,43 0,052			0,453 0,039	0,466 0,033					0,4 0,073	0,377 0,092		
			works of preventive maintenance																	
			works of predictive maintenance																	

Table 107: correlation human resource 2/2 - level of implementation of information flows

Risorse umane			Implementation of information flows																
			C-DDD	DDD -DDR	MED -RCMD	RCMD-DDD	MMO-RPO	MED-DDD	RCMO-MMO	MEO-MMO	MNT/OP-SIO	RPO-MEO	SIO-RPO	SIO-MEO	MNT/OP-MMO	MMO-DDR	MMO-MNT/OP	MEO-DDR	RVP-DDR
WHOLE SAMPLE	Degree of involvement of production operators in	routine maintenance interventions	0,299 0,035										-0,272 0,056		0,291 0,04	0,316 0,025			0,306 0,031
		resettlement of simple breakdowns	0,314 0,026	0,366 0,009									-0,27 0,057			0,335 0,017	0,373 0,008	-0,24 0,093	0,32 0,023
		works of preventive maintenance							-0,235 0,1					-0,235 0,1					
		works of predictive maintenance										0,288 0,042							
PAPER SECTOR	Degree of involvement of production operators in	routine maintenance interventions																	
		resettlement of simple breakdowns									-0,522 0,015								
		works of preventive maintenance																	
		works of predictive maintenance																	
C/F SECTOR	Degree of involvement of production operators in	routine maintenance interventions	0,376 0,093		0,376 0,093	0,376 0,093	0,376 0,093	0,376 0,093				0,376 0,093			0,449 0,041	0,432 0,05	0,476 0,029		0,376 0,093
		resettlement of simple breakdowns		0,517 0,017							0,376 0,093					0,409 0,066	0,622 0,003		
		works of preventive maintenance									0,568 0,007		0,4 0,072						
		works of predictive maintenance									0,463 0,034								

To conclude this analysis, the correlation between the levels of implementation of areas, software and information flows and the degree of involvement of production operators in maintenance tasks has been analyzed. Few correlations have been found; the most interesting are those of the paper sector, where to a greater implementation of the MEO and RPO areas correspond a lower level of involvement. This result can be explained considering that a greater level of implementation of MEO and RPO areas means a greater complexity of the plant (this is partially confirmed by table 88) and, therefore, the need of more qualified personnel for the reparations.

9.4 Conclusions of the chapter

With the term "*catalysts*" in this works are intended all those elements that promote the implementation of areas, software and information flow. In this chapter the author has identified the following catalysts:

1. *Company size (in terms of revenue and workforce)*: in particular the revenue is an important driver for the adoption of CMMS systems. Company size influences positively the level of implementation of maintenance areas, software and flows (especially for the paper sector and the whole sample) and negatively the involvement of

production operators in maintenance tasks. In fact, as the revenue increases, it is observed a greater availability of qualified personnel;

2. *Maintenance strategy (in terms of workforce)*: a strong positive correlation has been found between the number of qualified maintenance technicians, supervisors and graduated engineers and the level of implementation of maintenance areas, software and flows. This result highlights that one of the most important catalysts is the presence of "maintenance knowledge" in the company, ensured by the presence of qualified and trained personnel;
3. *Human resource (in terms of time spent every year in training on issues of maintenance)*: the considerations expressed above in the point 2 are highlighted by the strong correlation found between the average time spent in training on issues of maintenance and the level of implementation of the various elements of the reference model. The maintenance culture is one of the main drivers for the introduction of new maintenance approaches and methodologies;
4. *Technical variety*: even if only for the chemical/pharmaceutical sector, a positive correlation of technical variety with predictive maintenance techniques and the adoption of many CMMS modules was found. Positive correlations were found also with the level of implementation of many areas, software and flows;
5. *Continuous type manufacturing strategy*: the strong positive correlations found show that this type of production pushes companies to implement areas, software and information flows (especially those of the design and revamping phase). It is clear, however, that companies that adopt this production process are large enterprises with high revenues;
6. *Maintenance planning and control system (CMMS)*: the computerization and the adoption of a big set of CMMS modules represent a necessary prerogative for the implementation of areas, software and information flows.
7. *Phases of the lifecycle that involve directly the company (plant lifecycle)*: this element is a catalyst for the whole sample. Greater is the portion of lifecycle managed by the company and greater are the knowledge and the skills of the maintenance personnel: this pushes the implementation of maintenance tools and the investments on training. Moreover corrective maintenance policies decreases in favor of preventive and predictive policies;

Concerning the barriers to the implementation of areas, software and information flow (the so-called "*inhibitors*"), the author has identified the following elements:

1. *Small batch type manufacturing strategy*: if continuous type, manufacturing strategy is an important catalyst, while if small batch type, manufacturing strategy prevents (or at least does not encourage) the implementation of maintenance tools and methodologies and the adoption of CMMS systems. It promotes the training of operators because the lack of qualified maintenance personnel requires the participation of operators in the maintenance tasks;
2. *Technical complexity*: more than a real barrier, technical complexity affects negatively some time needed to execute the maintenance tasks, as the time needed to restart the plant. However, negative correlations with the implementation of areas, software and information flows were found, especially for the chemical/pharmaceutical sector and the whole sample.
3. *Maintenance strategy (in terms of adoption of corrective maintenance)*: maintenance policies of this type were observed in those companies where, because of a lack of knowledge or resources, there was observed a low implementation of maintenance tools. In general it can be said that where the corrective maintenance is ex-

tensively used, often there is a **lack of "maintenance culture" and this element can be considered, together with the lack of economic resources, the real barrier to the implementation of maintenance tools, approaches and methodologies**.

This is particularly true especially for the paper.

These results are showed in the following table. The format of every element (the dimension) indicates its importance: for example, in the whole sample "Company size" and "technical variety" are important catalysts, but "Company size" has an influence greater than the "technical variety".

Table 108: barriers and success elements to the implementation of integrated solutions

	WHOLE SAMPLE	PAPER SECTOR	C/PH SECTOR
CATALYSTS	**Company size;** **Maintenance strategy (workforce);** **CMMS**; Human resource (training); Continuous type manufacturing strategy; Lifecycle; Technical variety.	**Company size;** **Maintenance strategy (workforce);** CMMS.	**Technical variety;** **maintenance strategy (workforce)**; CMMS; Human resource (training); Continuous type manufacturing strategy.
INHIBITORS	Small batch type manufacturing strategy; Technical complexity.	Maintenance strategy (corrective maintenance).	Technical complexity; Small batch manufacturing strategy.

10. Fifth aim

The purpose of this chapter is the "*assessment of the potential interest of companies for a future implementation of integrated solutions*", answering the fifth aim exposed on Section 1.2. In order to understand the direction taken by companies in terms of innovation, the author has measured the three levels of future implementation of areas, software and information flows. Then the author has calculated the correlations between these three different elements to understand if there is a dependency between the intention to adopt new areas and the intention to implement new software and new information flows.

To conduct this analysis, the answers to the following questions have been considered:

- question n°26, only for what concerns the future implementation (or update) of the various areas of the reference model;
- question n°30, only for what concerns the future implementation of software.
- question 31, only for what concerns the future implementation of the information flows of the reference model.

10.1 Future implementations planned by companies

Below are reported the results concerning the future implementations of areas, software and information flows, planned by the companies interviewed:

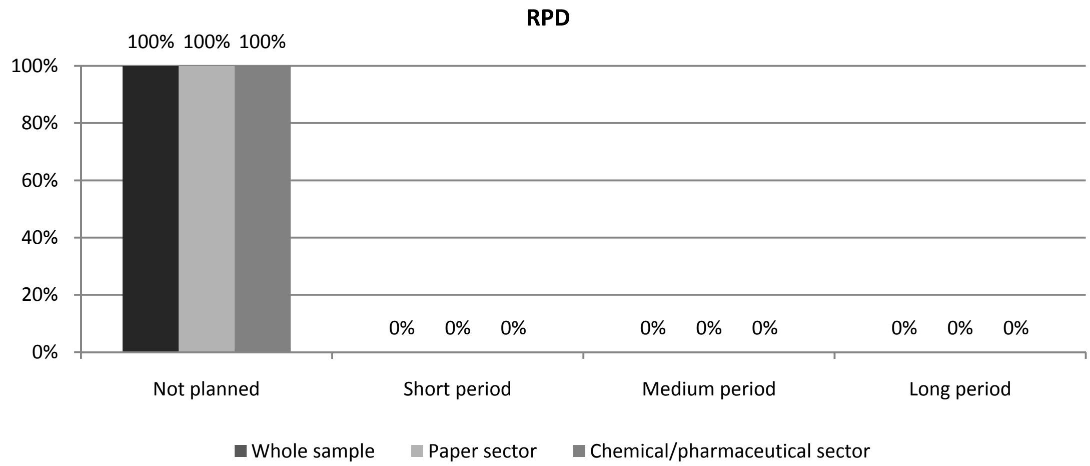


Figure 101: future implementation of the RPD area

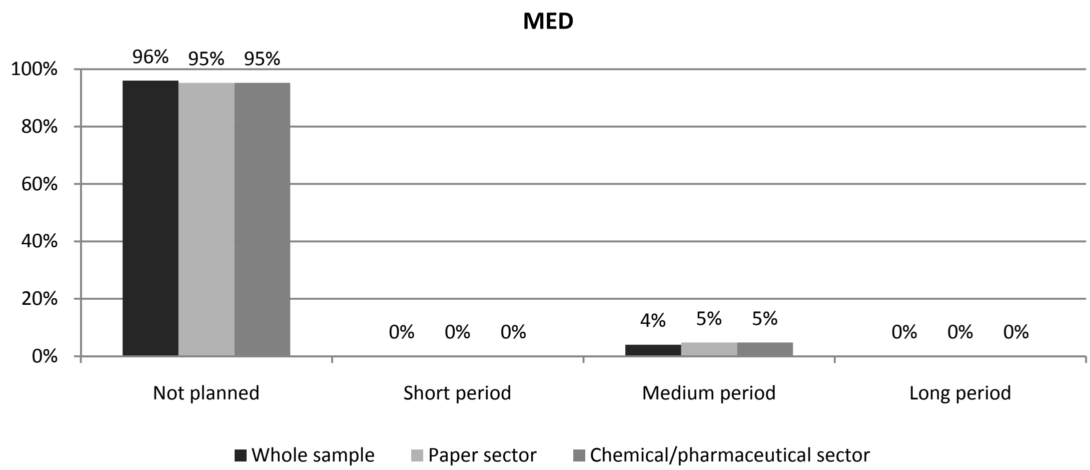


Figure 102: future implementation of the MED area

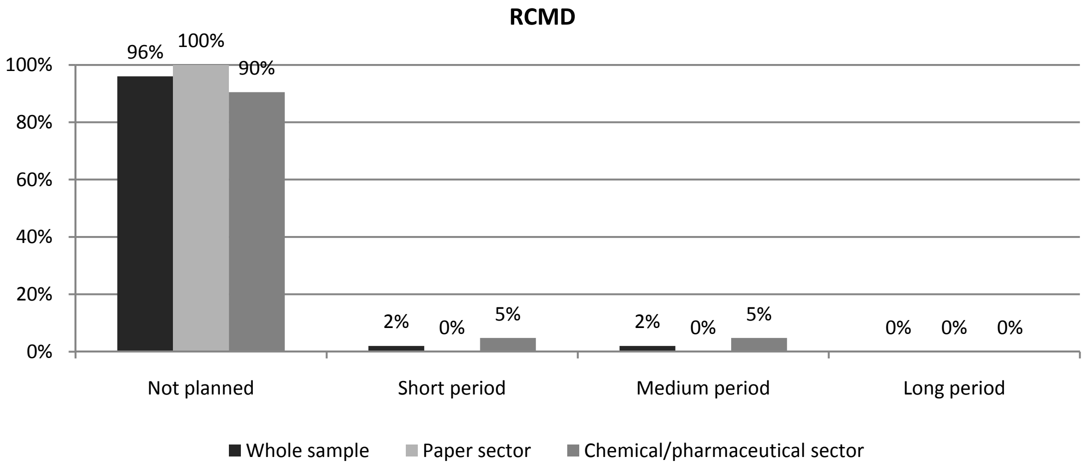


Figure 103: future implementation of the RCMD area

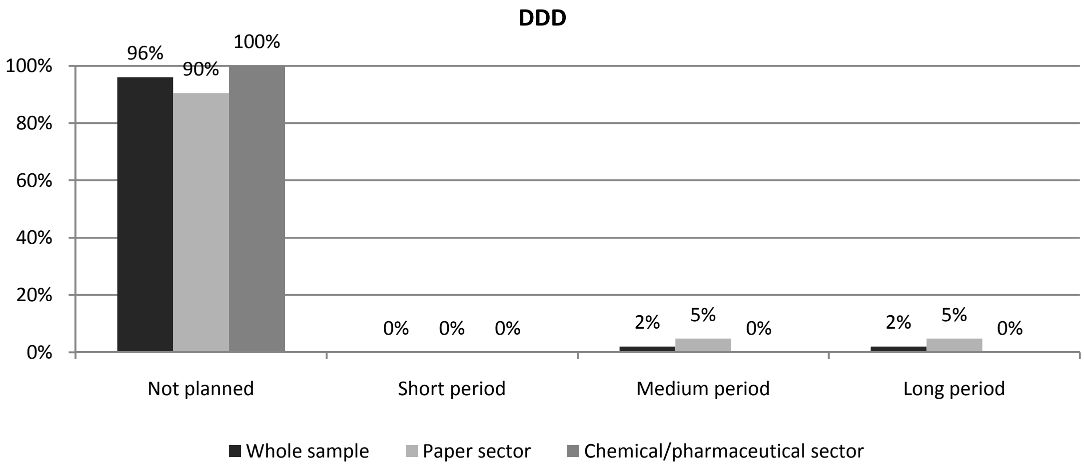


Figure 104: future implementation of the DDD area

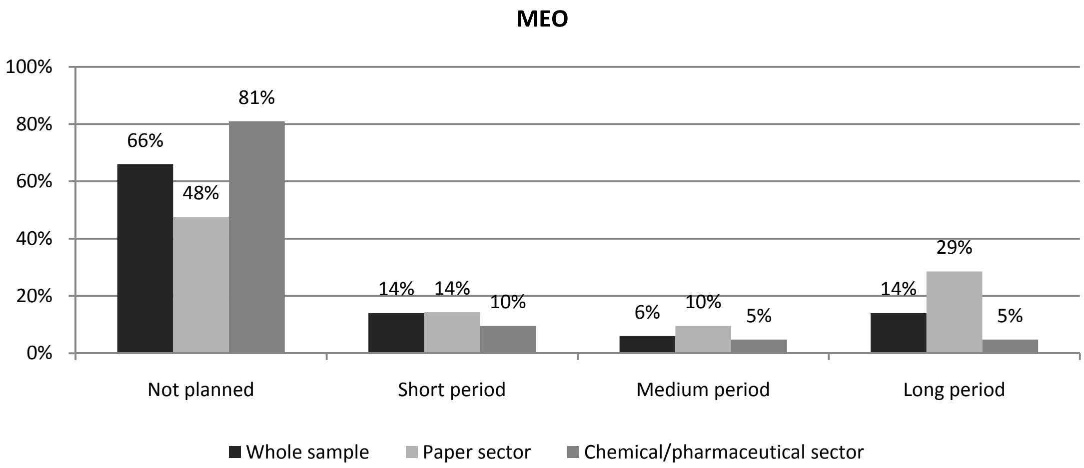


Figure 105: future implementation of the MEO area

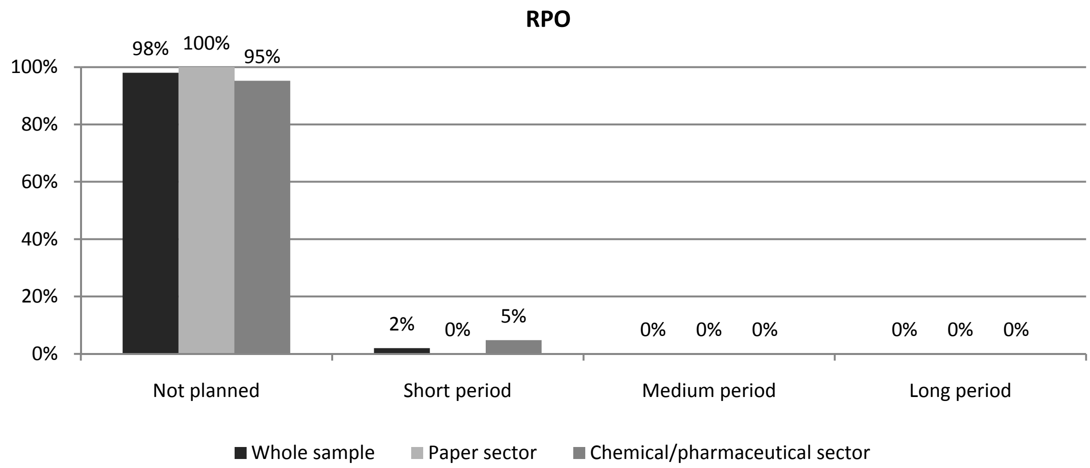


Figure 106: future implementation of the RPO area

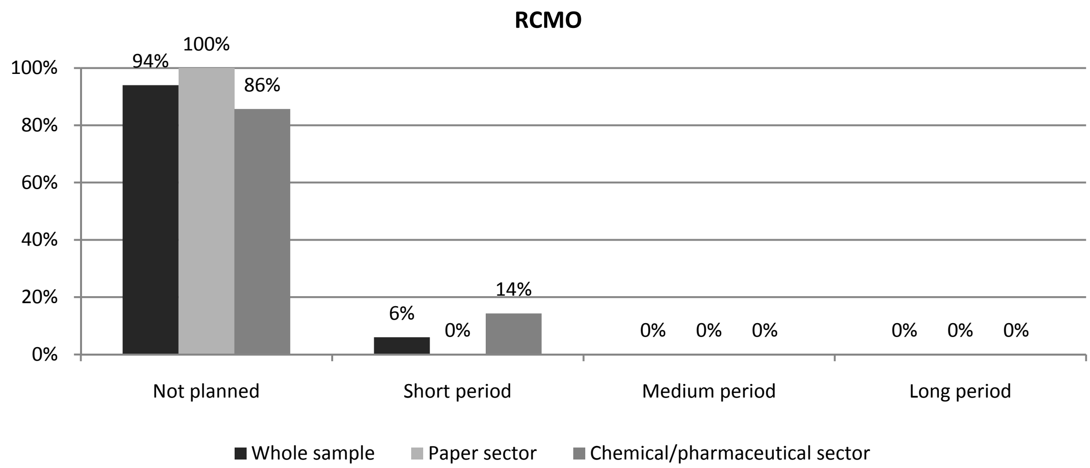


Figure 107: future implementation of the RCMO area

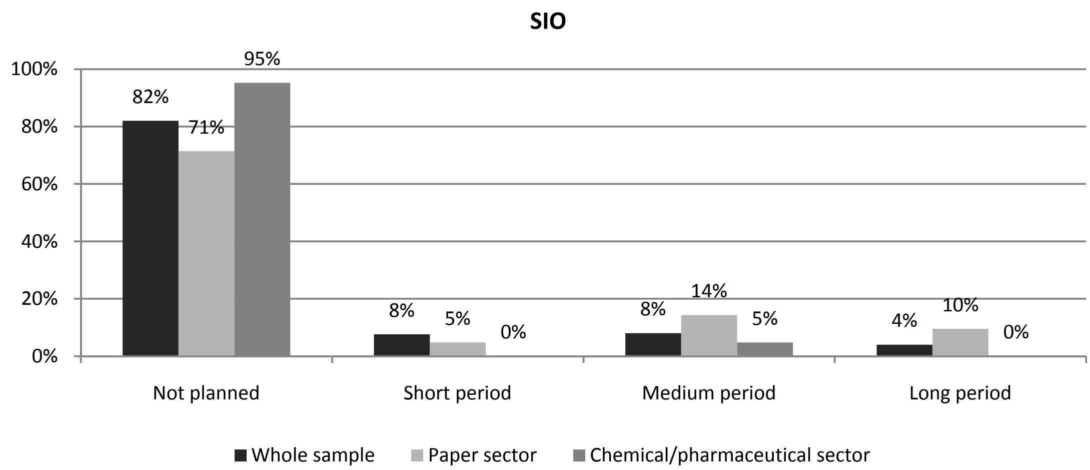


Figure 108: future implementation of the SIO area

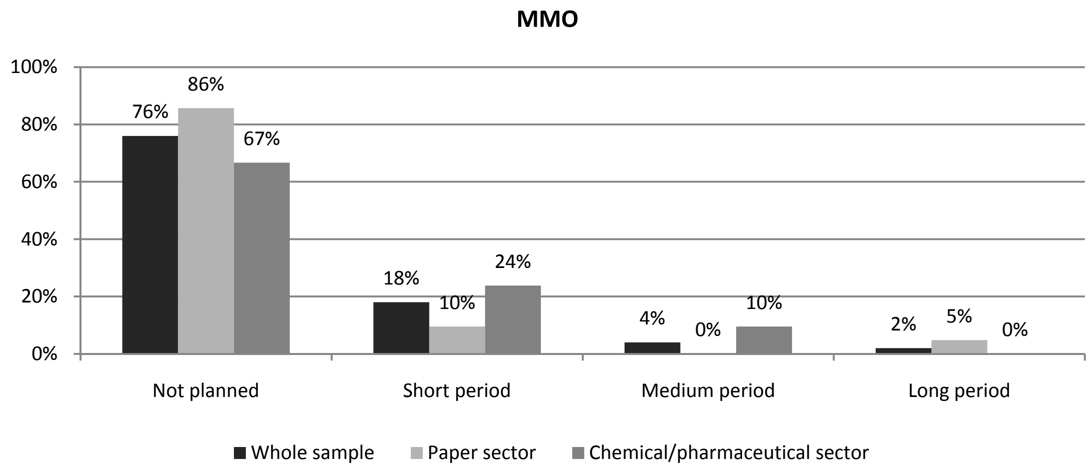


Figure 109: future implementation of the MMO area

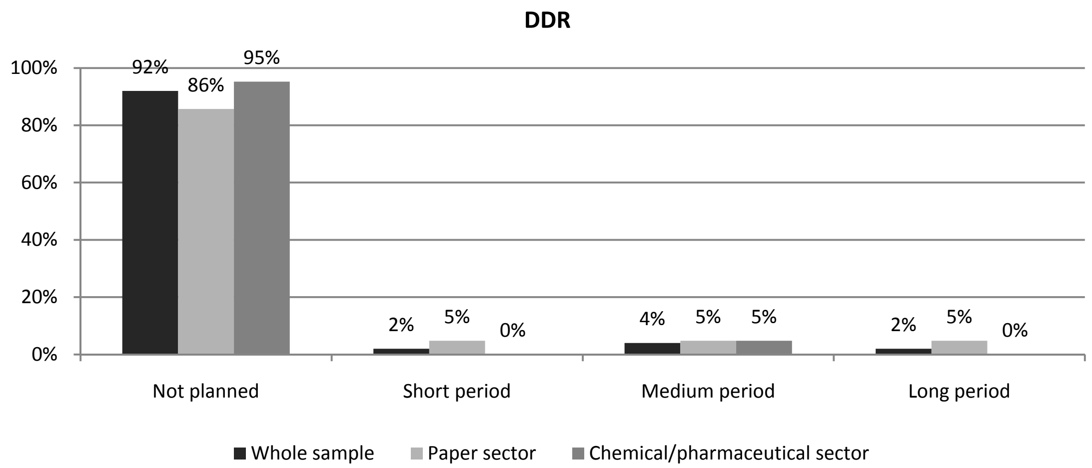
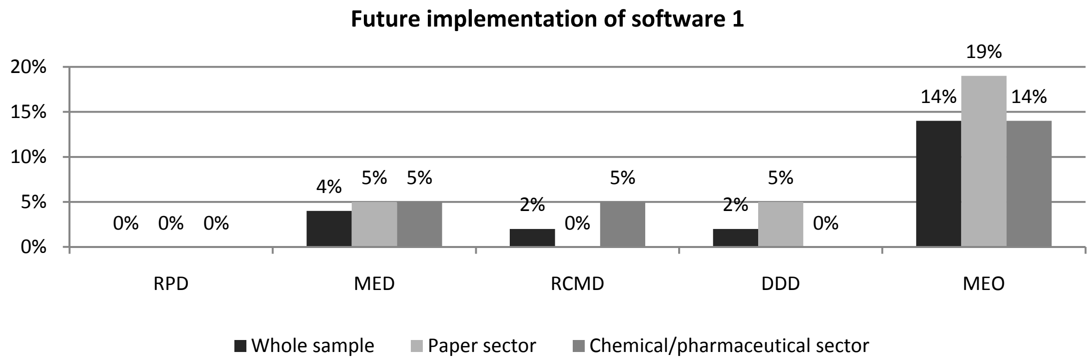


Figure 110: future implementation of the DDR area

In these graphs the whole sample is compared to the two industrial sectors. Considering only the design phase, the level of future implementation of areas is close to zero. Considering also that the current implementation of such areas is low, this result highlights another time that companies do not have interest in investing in maintenance during the design stage, not understanding the importance of this phase for the effectiveness of the maintenance process during the operational phase. Some companies have expressed the intention to implement in the medium term the MED and RCMD areas: for the first area is observed a substantive similarity between the two industrial sectors, while the intention to adopt the second area is emerged only in the chemical/pharmaceutical companies (is not a real new implementation, but an extension of the RCM adopted during the operational phase to the design phase).
From the perspective of the operational phase, the situation still presents very low levels of future implementation, but higher than those of the design phase. Is observed a moderate interest by companies of the paper sector in the MEO area (over 50% of companies); this area is already heavily implemented by this sector, but often without a proper organization and computerization. Their interest, therefore, focuses on improvements of the existing MEO area (this consideration is strengthened by the fact that approximately 19% of paper companies have planned a future implementation of software for the MEO area). The paper sector is also interested in future implementations and upgrades concerning the SIO area (which, as mentioned in the previous chapters, is widely implemented by this sector).

For what concerns the MMO area, the biggest interest in future implementations/upgrades is showed by the chemical/pharmaceutical sector (that already implement this area). This sector is also interested in the implementation of the most advanced areas of all the maintenance process, such as the RCMO and RPO areas (highlighting another time the "cultural gap" present between the paper sector and the chemical/pharmaceutical sector).

For what concerns the future implementation of special purpose software, the results are showed below:



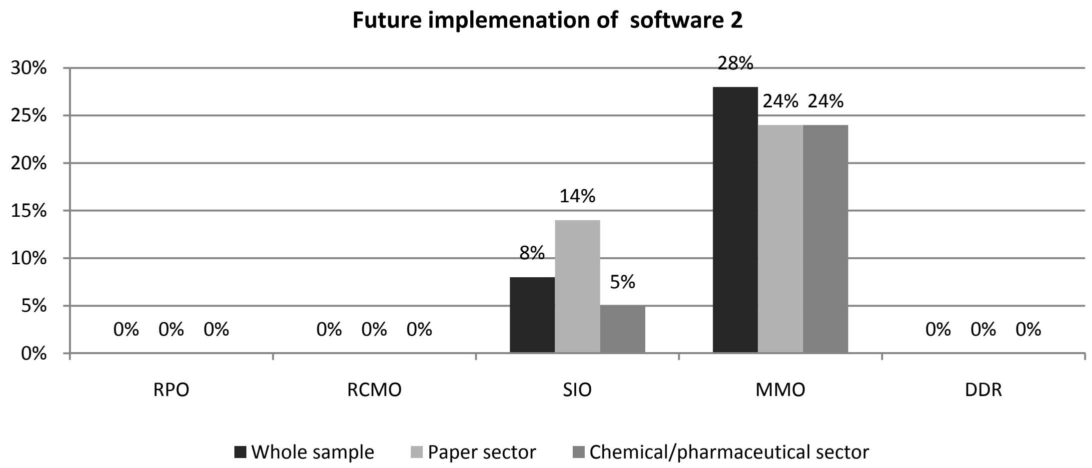
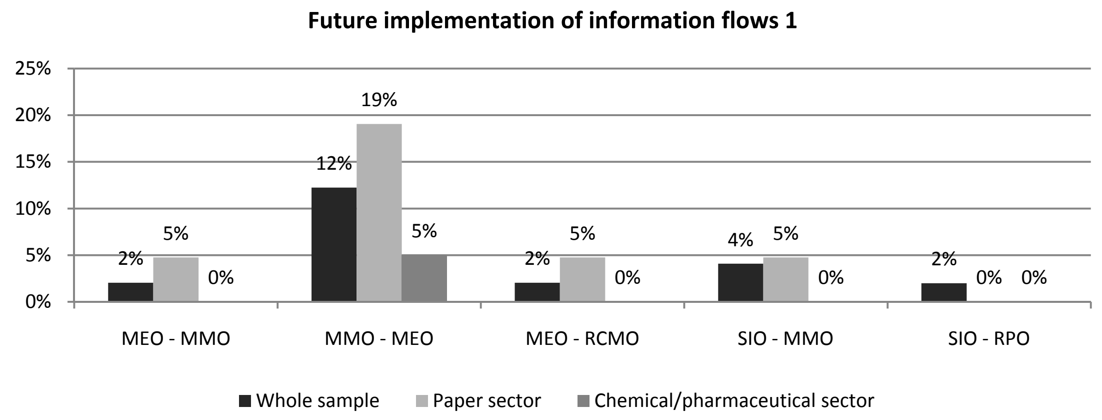


Figure 111: future implementation of special purpose software

For the RPD, RPO, RCMO and DDR areas is not observed any future implementation of software and this could partially explained by the fact that these areas (excluding the DDR area for which, however, are already strongly used CAD software) are in general poorly implemented.
For MED, RCMD and DDD software the percentages are low: for the first two this is due to the fact that the related areas are poorly implemented, for the DDD the question is different: the DDD is an activity strongly adopted, where the use of software is of essential importance. These software often are CAD solutions, highly standardized and popular for a long time, therefore companies do not have a strong need to update these tools.
Software that present the highest values for a future implementation are those of the SIO, MEO and MMO areas. In recent years these activities have grown in importance and many software solutions are present on market. Because of the nature of these areas, the related software need frequent updates: for example, a plant revamping necessarily leads to up-

grades of the SIO area; at the same time, the CMMS must be updated to correctly work. The considerations related to the MEO software are the same exposed before concerning the MEO area.

The results concerning the future implementation of information flows are as follows:



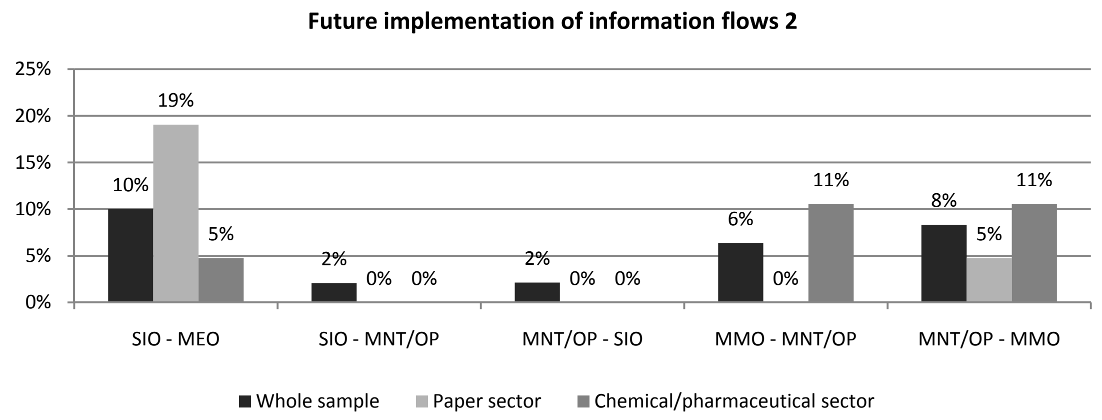


Figure 112: future implementation of information flows

In the two figure above are reported only those flows for which companies have shown interest in a future implementation.
Most of these flows involve the SIO area; this area, because of its characteristics, is strongly dependent on the information flows. The other flows are those that involve activities such as MMO, MEO and MNT/OP. Compared to all the results so far obtained, in this case it was observed a more dynamic behavior of paper sector companies, especially for those flows that involve the MEO and MMO areas.
It is interesting the comparison between the flows MMO-MNT/OP and MNT/OP-MMO: it is evident how chemical/pharmaceutical companies have better understood the usefulness of the CMMS, which is not used as a simple database for collecting data from field or from other areas (this is confirmed also by the study of the current level of adoption of the flow MMO-MNT/OP). The companies of this sector are in fact the only ones that have planned a future implementation of information flows from the MMO area to the operational phase MNT/OP, by sending for example the maintenance plans updated to the operator's PDAs.

10.2 *Analysis of the correlations between the levels of future implementation*

To properly carry out considerations about the planned future implementations, a correlation analysis has been performed in order to observe if a future implementation of a specific area is correlated with the future implementation of a specific software or information flow. The correlations analyzed have been those between:

- the future implementation of areas and the future implementation of software;
- the future implementation of areas and the future implementation of information flows.

The following table shows the first correlation; is expected a correlation between the intention to implement or update an area and the intention to adopt a software for that specific area.

It has been used the same format of the correlation tables of the previous chapter,: the yellow-colored boxes are those where the p-value is between 5% and 10%; the boxes with the text in red contain negative Pearson correlation coefficient; boxes with standard format have a p-value less than 5% and positive Pearson correlation coefficient.

Table 109: correlation future implementation of areas - future implementation of software 1/2

Future implementation of software		Future implementation of areas: MED	RCMD	DDD	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	MED	**0,98 0**	0,477 0	0,44 0,001	0,543 0	0,286 0,044	0,37 0,008	0,582 0	
	RCMD		**0,433 0,002**						
	DDD	0,7 0		**0,543 0**			0,481 0	0,592 0	
PAPER SECTOR	MED			0,525 0,014			0,509 0,018	0,904 0	
	RCMD								
	DDD			**0,525 0,014**			0,509 0,018	0,904 0	
C/F SECTOR	MED		0,89 0			0,548 0,01			
	RCMD		**0,411 0,064**						
	DDD								

There are no negative correlations and almost all the boxes have p-value less than 5%. Another formatting criterion has been added: in bold are formatted those boxes that show a significant correlation between the area and the corresponding software. The analysis of the whole sample highlights this correlation: each future implementation of one area is correlated with the future implementation of the specific software: this indicates that the evolution of the maintenance processes and methodologies goes hand in hand with the evolution of the IT tools.

In this comparison, an important correlation observed in the design phase is that between the future implementation of the MED area and the future implementation of the related

software (p-value null and Pearson correlation coefficient close to 1). In the design phase, the future implementation of software in MED is also correlated with the future implementation of the RCMD and DDD areas: the informatization of the MED area is a prerogative for the subsequent implementation of advanced areas such as the RCMD (this is also highlighted by the correlation with the RPO and RCMO areas of the operational phase).
The future implementation of software in the RCMD area is correlated only with the future correlation of the RCMD area itself; this result probably is due to the low number of companies interested in this implementation.
Future implementations in software for the DDD area, instead, are correlated with future implementation of the DDD (and this result is obvious, because the implementation of the DDD area without the adoption of software has no sense), MED, MMO and SIO areas.
Similar results are observed in the two industrial sectors, but few in number.
Observing the table 109 and also the table 110 below, it is possible to note that future implementations of software are correlated almost always with future implementation/upgrade of the MMO area. This result was expected: in fact, because of the central role of the MMO, each modification/implementation of software in other areas means updates or modifications of the MMO area.

Table 110: correlation future implementation of areas - future implementation of software 2/2

Future implementation of software			Future implementation of areas: MED	RCMD	DDD	RPO	RCMO	SIO	MMO	DDR
	WHOLE SAMPLE	SIO	0,412 0,003		0,312 0,027			**0,385 0,006**	0,29 0,041	
	WHOLE SAMPLE	MMO	0,409 0,003						**0,475 0**	
	PAPER SECTOR	SIO	0,616 0,003					**0,386 0,084**	0,52 0,016	
	PAPER SECTOR	MMO	0,746 0					0,467 0,033	**0,718 0**	
	C/F SECTOR	SIO		0,411 0,064						
	C/F SECTOR	MMO								0,501 0,021

Analyzing the results of the table 110, emerges that a future implementation/upgrade of software of the SIO area is correlated with future implementations of the MED and DDD areas of the design phase and the SIO and MMO of the operational phase. The correlations with SIO and MMO are evident for the considerations above expressed, those with the areas of the design stage can be justified, considering that the SIO area and its software must be considered since the first design of the plant.
Concerning the future implementation of software of the MMO area is evident the strong correlation with the correspondent are. Were expected also strong correlations with the future implementations of the other areas, because of the central role of the CMMS. However this result wasn't obtained with the sample interviewed.

Passing to the study of the correlations between the future implementation of areas and the future implementation of information flows, the results are showed in the following three tables:

Table 111: correlation future implementation of areas - future implementation of information flows 1/3

Future implementation of informa info flows			Future implementation of areas: MED	RCMD	MEO	RPO	RCMO	SIO	MMO	DDR
	WHOLE SAMPLE	MEO-MMO								0,517 0
		MMO-MEO						0,341 0,015	0,284 0,046	0,324 0,022
		MEO-RCMO					0,268 0,06			0,54 0
	PAPER SECTOR	MEO-MMO								0,429 0,052
		MMO-MEO	0,429 0,052					0,434 0,049	0,421 0,058	
		MEO-RCMO								0,381 0,089
	C/F SECTOR	MEO-MMO					0,548 0,01		0,533 0,013	
		MMO-MEO						0,689 0,001	0,527 0,014	0,689 0,001
		MEO-RCMO					0,548 0,01		0,533 0,013	

The first consideration concerns the correlation between the future implementation of the DDR area and the future adoption of the main information flows related to the maintenance engineering of the operational stage (MEO): to implement or update the area voted to the revamping, it is necessary to implement or update flows that transfer information between the CMMS and the MEO areas (the decision of a revamping, in fact, starts from the MEO area and passes through the MMO area).
The other areas influenced by a future implementation of the flow between the MMO and MEO areas (in this case the direction MMO-MEO) are the SIO and the MMO areas. The reinforcement of this information flow influences both the process of data collecting from field and the process of data management.
Finally, it was highlighted how for a proper implementation of the RCM area it is necessary to enable the information flow between the MEO and the RCMO areas: the information from the MEO (together with those that are collected in the CMMS) helps to implement the principles of the RCM approach. These considerations emerged considering prevalently the whole sample, however the results concerning the two industrial sectors are similar: in the chemical/pharmaceutical sector it is possible to note that the future implementation of the RCM is correlated not only to the adoption of the MEO-RCMO flow but also to the flow that allows the exchange of information between the CMMS and the MEO (this highlights a good control of the maintenance process by the companies of this sector, because the in-

formation flow that from the MMO goes to the RCM, needs also the flow that allows the exchange of information between the CMMS and the MEO areas: the MEO-MMO flow).

Table 112: correlation future implementation of areas - future implementation of information flows 2/3

Future implementation of informa info flows		Future implementation of areas: MED	RCMD	MEO	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	RCMO-MMO					0,565 0		0,371 0,008	0,407 0,003
WHOLE SAMPLE	MMO-RCMO					0,565 0		0,371 0,008	0,407 0,003
WHOLE SAMPLE	SIO-MMO			0,235 0,1			0,324 0,022		
PAPER SECTOR	RCMO-MMO								
PAPER SECTOR	MMO-RCMO								
PAPER SECTOR	SIO-MMO								
C/F SECTOR	RCMO-MMO					0,548 0,01		0,533 0,013	
C/F SECTOR	MMO-RCMO					0,548 0,01		0,533 0,013	
C/F SECTOR	SIO-MMO								

The considerations above reported are confirmed by the table 112 (for the paper sector no significant correlations were found, also because in this table are considered mainly the flows related to the RCM, area not implemented by the paper companies):

- innovations in flows related to the RCM area are positively correlated with innovations in the RCM, MMO and DDR areas;
- an update of the SIO area implies an update of the information flow between this area and the CMMS.

Table 113: correlation future implementation of areas - future implementation of information flows 3/3

Future implementation of informa info flows		Future implementation of areas: MED	RCMD	MEO	RPO	RCMO	SIO	MMO	DDR
WHOLE SAMPLE	SIO-MEO						0,337 0,017		
WHOLE SAMPLE	MMO-MNT/OP	0,557 0	0,719 0		0,814 0	0,44 0,001		0,25 0,08	
WHOLE SAMPLE	MNT/OP-MMO	0,332 0,019	0,435 0,002		0,502 0	0,251 0,078		0,278 0,05	

PAPER SECTOR	SIO-MEO						0,399 0,073		
	MMO-MNT/OP								
	MNT/OP-MMO								
C/F SECTOR	SIO-MEO		0,411 0,064						
	MMO-MNT/OP	0,89 0	0,781 0		0,89 0	0,458 0,037			
	MNT/OP-MMO	0,89 0	0,781 0		0,89 0	0,458 0,037			

Studying the correlations related to the future implementation of the information flows between the production system (MNT/OP) and the MEO (via SIO) and the MMO areas, it is possible to argue, even considering the previous tables, that there is a direct correlation between the innovation of the SIO area and the corresponding information flows with the MEO and the MMO areas. More evident are the correlations between the MMO-MNT/OP and MNT/OP-MMO flows and the main areas of the maintenance process, both in the design phase (MED and RCMD) and in the operational phase (RPO, RCMO and MMO). The correlation with the operational phase of the system was expected, because of the role of the CMMS as data source for the activities of the RPO and RCMO areas.

10.3 Conclusions of the chapter

From the study of the results of this chapter it can be concluded that the companies studied do not plan future implementations in the design phase, but in the operational phase. For the paper companies often these implementations are introductions of new areas, software or flows, while for the chemical/pharmaceutical companies often are updates.

As expected, were found strong correlations between the future implementation of an area and the future adoption of software and information flows.

The main drivers that lead the innovation are the areas: a modification to an area implies the modification of the related software; modifications to different areas and software imply the introduction or modification of the related information flow.

Once again the central role played by the CMMS has been highlighted: almost all the future implementation of areas (but especially of software and information flows) result in the need to update the CMMS.

11. Conclusions

This work aims at answering two research questions:

a) **which is the current level of knowledge, implementation and automation of maintenance approaches, methodologies and tools, integrated along the plant lifecycle?**
b) **which are the barriers and the success elements for their penetration**?

To do this, these research questions have been split up into five aims:

1) assess the current level of knowledge, implementation and automation in companies of:
   - ✓ integrated methodologies, approaches and tools for maintenance;
   - ✓ special purpose software;
   - ✓ information flows;
2) assess if companies, that have implemented such integrated solutions for maintenance, use them along the lifecycle of their production plant;
3) investigate the correlation among several company's structural variables and the maturity level of adoption of integrated methodologies, approaches and tools for maintenance along the plant lifecycle;
4) identify the success elements and the barriers that promote or inhibit this integration;
5) assess the potential interest of companies for a future implementation of integrated solutions.

The methodology adopted has been the survey based research. The survey has been submitted to 50 companies that performs maintenance on their own plants, 21 of these companies belong to the chemical/pharmaceutical sector, 21 to the paper sector and 8 to other sectors.

11.1 First aim

The analysis of the first aim has been carried out in the Chapter 6.

In terms of **level of implementation**, the most implemented areas in the design phase are the MED and DDD areas both for the paper and chemical/pharmaceutical sectors. The operational phase, in average, presents levels of implementation higher than the design stage: in the paper sector the predominant areas are MEO, SIO and MMO, while in the chemical/pharmaceutical are MEO, MMO and DDR.

Table 114: most implemented areas

	Most implemented areas
Paper sector	MEO SIO MMO
Chemical/pharmaceutical sector	MEO MMO DDR

This result highlights that the chemical/pharmaceutical companies cover a portion of the plant life cycle bigger than the portion of the paper industry: this means that this companies, thanks to the knowledge and information collected during the operational stage, together with a complete control of all the production and maintenance process, are able to continuously improve the system by revamping activities (DDR).

In the paper sector the SIO area is predominant: in fact for these companies is fundamental the real-time control of all the assets parameters, while for the chemical/pharmaceutical companies is more important the control of the product quality (this is underlined by the importance, for this sector, of the information flow between the operational phase MNT/OP and the CMMS).

All these considerations, including those related to the information flows, should be considered taking into account the effective number of companies that implement the various areas:

Table 115: number of companies that implement the following areas:

	RPD	MED	RCMD	DDD	MEO	RPO	RCMO	SIO	MMO	DDR
Whole sample	**2**	6	**1**	19	40	**3**	7	28	41	29
Paper sector	**0**	**3**	**0**	9	19	**1**	**1**	15	15	9
C/F sector	**0**	**2**	**1**	8	15	**1**	**4**	8	19	16

A more detailed analysis has shown that the level of implementation of the areas of the design phase is lower than those of the operational phase (almost always medium or low, while the areas of the operational stage show medium or high levels of implementation: see for example the results concerning the MMO, MEO, SIO and DDR areas).
In general, the chemical/pharmaceutical companies present levels of implementation higher than those of the paper companies. The differences are more pronounced if the comparison is not done on the basis of the industrial sector, but on the basis of the company size (in terms of annual revenue). Only the big enterprises present levels of complete implementation and implement the most advanced maintenance techniques such as the RCM and RPO areas.
To study in depth the levels of implementation of the areas, it has been carried out a vertical analysis (an analysis able to evaluate the simultaneous presence of different areas along the vertical axis of the reference model): this analysis has identified the simultaneous presence of several areas that operate on the same phase of plant lifecycle (such as MEO+MMO, SIO+MMO, SIO+MEO e MED+DDD). The aim of this analysis has been to understand if the presence of an area influences the presence of another area of the same phase of the plant lifecycle. The Pearson correlation coefficients and the P-values have been calculated for every possible couple of areas belonging to the same lifecycle stage. The positive and significant correlations identified have been:

- Design stage: those between the RCMD, DDD and MED areas;
- Operational phase: all areas have significant correlations, except the two most adopted areas MEO and MMO. This is probably due to the fact that many companies implement these areas independently of each other.

The SIO and MEO areas have shown a significant correlation only for the paper sector (where the importance of the process control is very high).

From the point of view of the implementation of specific maintenance engineering methodologies, it was found that the only methodologies adopted are the FTA, FMECA and HAZOP analysis (present both in the design phase and in the operational phase): the percentages of adoption, however, are very low, below 10% (only considering the chemical/pharmaceutical sector these percentages go up, but still lower than 20%).

From the perspective of the software, their levels of implementation go hand in hand with the respective areas, also in this case the chemical/pharmaceutical sector presents levels of implementation higher than paper sector.

Concluding the study of the current levels of implementation with the analysis of the information flows, it has been found that those most adopted are: MMO-MEO, MMO-MNT/OP and MNT/OP-SIO. As expected, these flows are those exchanged between the most implemented areas. The adoption of information flows in the paper sector is lower

than in the other sector. In part this difference can be explained by the fact that, on average, paper companies have levels of implementation of the areas lower than chemical/pharmaceutical companies. The differences between the two sectors are more pronounced in the design phase and decrease during the operational phase.
The only two exceptions are the SIO-MMO and the SIO-MEO flows because of the most intensive implementation of the SIO are in the paper sector.

For what concerns the assessment of the **level of automation**, the author has analyzed the level of adoption of ERP and CMMS in the companies interviewed, the level of adoption of special purpose software for each area of the model and the level of automation of the information flows.
Concerning the typology of CMMS adopted:

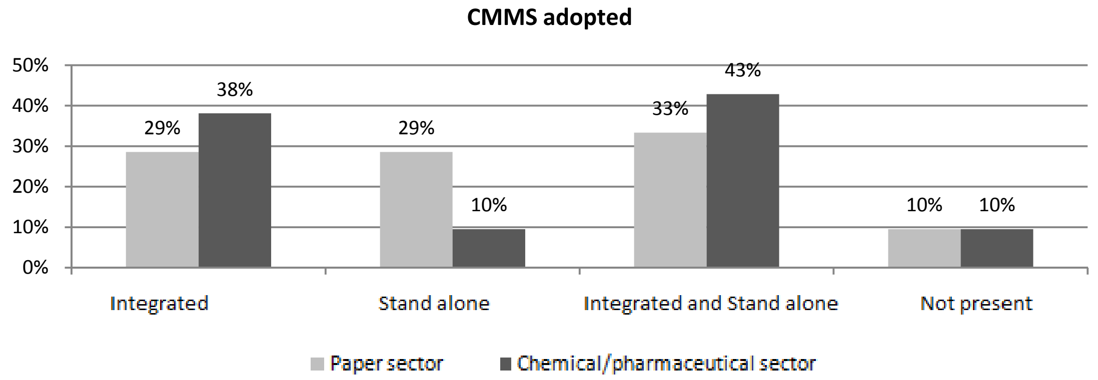


Figure 113: typology of CMMS adopted (paper sector and chemical/pharmaceutical sector)

Many companies adopt the CMMS integrated with the ERP and in some case use it in combination with a stand-alone software. Only a small percentage of companies do not use any type of CMMS. The main activities for which the CMMS is implemented are shown in the table below:

Table 116: main activities for which the CMMS is implemented (paper sector and chemical/pharmaceutical sector)

	Paper sector	Chemical/pharmaceutical sector
1	Planning of maintenance activities (preventive and predictive)	Planning of maintenance activities (preventive and predictive)
2	Data recording of works performed	Data recording of works performed
3	Data reporting of maintenance works performed	Planning and scheduling of work orders

It has been verified that companies, that use the CMMS as a “data base for availability/reliability analysis”, present a strong vertical integration of some areas, such as MEO+MMO, SIO+MMO, SIO+MEO and MED+DDD.
Moreover, the survey has shown that the software most used in the main areas are:
- Design/revamping: AutoCad;
- Maintenance Engineering: Maximo, Datastream and CoreMaint;
- Process Control: customized software;
- CMMS: SAP, Maximo and Datastream.

Have been also identified the most interesting flows(from the point of view of the typology of communication: MMO-MEO, MMO-MNT/OP, MNT/OP-MMO, MEO-DDR e SIO-MEO.

Finally, for what concerns the assessment of the **level of knowledge**, it has been analyzed the difference between the importance perceived and the potential importance of areas, software and information flows. The main results obtained are as follows:

- MEO - the level of knowledge of this area is good: the values of importance perceived and potential importance are both quite high (and consequently the gap between them is almost null). From the perspective of software, in large companies there is a good knowledge of the potentialities of the solutions adopted, while in the medium enterprises the awareness of the limited functions of the systems currently adopted (often based on Excel) matches the awareness that with simple changes such tools could become more useful (and this is evidenced by the large gap between the two importance).
- MMO – as the company size increases, also the importance perceived and the potential importance increase both for areas and for software. For the area, can be done the same considerations made for the MEO area. For software, instead, it is observed a moderate level of knowledge by the large and medium companies.
- SIO – also in this case can be done the same considerations made for the MMO area and for its software. In this case, the medium enterprises use the data supplied by the SCADA systems only to support and monitor the production. The fact that a discrete potential importance is attributed suggests that these companies be aware of the utility of these information also for maintenance.
- DDR - compared to the previous areas, here is more marked the proportionality between the company size and the level of implementation/knowledge. Concerning the software, in this case the knowledge is universal, because the software adopted are design programs such as CAD or derivatives;
- OTHER AREAS – for all the other areas, it has been found a strong correlation between the size and the level of adoption/knowledge (many areas such as RPD, MED, RCMD, RCMO and RPO are not implemented by the small and medium enterprises).

From the perspective of the level of knowledge of the information flows, the most significant flows analyzed have been: MMO-MEO, SIO-MEO, MNT/OP-MMO, MMO-MNT/OP e SIO-MMO. The paper sector presents a more dynamic behavior concerning the flows that involve the SIO area, while the chemical/pharmaceutical companies prevail for what concerns the flows exchanged between the CMMS and the operational stage MNT/OP. Also for the information flows the author has conducted an analysis of the difference between the importance perceived and the potential importance: in general, excluding the flows that involve the SIO area, for the others it can be observed a strong positive correlation of the importance perceived and potential importance with the company size, especially for those flows that involve the maintenance engineering. However, the general level of knowledge observed is quite low.

It has been also verified if to an implementation of some areas correspond an implementation of the related information flow: flows more implemented are those that involve the MMO and MEO areas, while flows that show the highest discrepancy between areas and flows implementations are those from SIO to MMO and from SIO to the operational phase.

At last, it has been performed a cross analysis, in order to measure the level of knowledge of the information flows, verifying for each flow if the information is simultaneously available (simultaneous presence of two areas), useful (future implementation planned) and used (presence of the flow). The results obtained show that:

- The level of implementation of the information flows during the design phase is almost null;
- The usefulness of the flow is almost null or at least not understood; the few companies that consider useful a flow are those for which this flow is also available and used;
- Flows that involve the DDD area and some areas of the operational phase (MMO, MEO, SIO and DDR) are those most available, only in some cases they are also used. The flows most implemented are those between the CMMS and the maintenance engineering (MEO), between the CMMS and the operational phase (MNT/OP) and between the operational phase and the activities of process control (SIO).
- Flows available, used and useful are limited to the information exchanged between SIO, MEO and MMO and the percentage of companies that belong to this category is very low.

This analysis has been performed also for each industrial sector and also classifying companies for size. The more relevant factors that influence the knowledge are related to the company size, and only in part to the industrial sector. In general, it was observed a very low level of knowledge of the information flows.

11.2 Second aim

The second aim has been studied, performing two different analysis:

- analysis of the simultaneous presence of some areas along the horizontal axis of the reference model (horizontal analysis);
- analysis of the correlation between the level of implementation of some areas and the phases of the plant lifecycle that involve directly the company.

The horizontal analysis focused on the simultaneous presence of the following areas: MED+MEO, DDD+MMO, DDD+MEO e DDD+DDR. The percentage of companies that implement these couples of areas are showed below:

Table 117: simultaneous presence of the following areas

	Whole sample	Paper sector	Chemical/pharmaceutical sector
MED + MEO	12%	14%	10%
DDD + MMO	24%	14%	33%
DDD + MEO	26%	24%	29%
DDD + DDR	24%	14%	33%

Excluding the MED+MEO couple, almost the 25% of the chemical/pharmaceutical companies implement simultaneously different areas of the reference model. This percentage is lower for the paper sector. Therefore, from the perspective of the use of integrated solutions, the results are poor, because no more than one-fourth of companies implements the couples of areas (and this only for companies of the chemical/pharmaceutical sector). From this point of view, it is possible to assert that the level of integration along the plant life cycle is very low. To confirm this thesis, a further analysis concerning the couples of areas above listed has been carried out: it has been assessed if companies, that implement the various couples of areas, adopt also the related information flow (which is essential for a complete integration of the maintenance system along the plant lifecycle). Also in this case, The percentages obtained are very low and confirm that the knowledge, by the companies, of the importance and usefulness of the information flows (and therefore of the importance of a maintenance system integrated along the plant lifecycle) is very low;

The second analysis has shown significative and positive correlations between the level of implementation of the MED, DDD, MEO, SIO and DDR areas and the phases of the plant lifecycle that involve directly the company. The design activities, that require high skills, are mostly implemented by those companies that manage large part of the plant life cycle.
From the point of view of the information flow, the analysis of the correlations with the plant life cycle has not present interesting results. The most significant results are those related to the flows between the DDD and DDR areas for the whole sample and the DDD-CBD and MEO-DDR flows for the chemical/pharmaceutical sector

11.3 Third and fourth aims

The third and fourth aims investigate the correlation among several variables in order to identify the success elements and the barriers that promote or inhibit the adoption of integrated maintenance methodologies, approaches and tools along the plant lifecycle;
The variables considered have been classified into three categories: "*company characteristics variables*", "*maintenance variables*" and "*implementation variables*".

Starting from the analysis of the correlations between the company characteristics variables and the maintenance variables, some structural variables have been observed that strongly influence the maintenance function, such as the revenue and the workforce. Especially the first one is an important driver for the adoption of the CMMS and of the related modules. Revenue is negatively correlated with the involvement of production operators in maintenance works: in fact, in some cases, companies with big revenues have plants advanced and complex that require qualified and trained personnel. Correlations between the revenue and the different types of maintenance policy (corrective, preventive and predictive) are not observed. The various maintenance policies are in fact related to other variables.
Also the lifecycle (intended as the phases of the plant lifecycle that involve directly the company) resulted a factor which directly influences the maintenance variables: more are the phases of the lifecycle directly managed by the company and greater is the number of maintenance technicians and supervisors. Also the maintenance policies are influenced by the lifecycle: companies that design their plants adopt, during the operational stage, preventive or predictive maintenance policies (and not corrective maintenance, because the control of different phases of the lifecycle allows the companies to have a better knowledge of their assets and therefore to prevent the failure). The number of graduated engineers is not correlated to the lifecycle because the role of a graduated engineer generally consists in the coordination of all the maintenance activities: therefore it is influent not the number, but the presence or not of engineers.
Concerning the manufacturing strategy, if "continuous process" type, this promotes the adoption of maintenance policies, also complex (as the predictive), that can reduce the breakdowns and increase the plant availability. Instead, companies that adopt "small batch" strategies are more directed to use more simple policies such as the corrective maintenance.
Concerning the technical variety, the results show that, for the whole sample and the paper sector, the correlation between the company characteristics variables and the maintenance variables is not evident, while it is quite strong for the chemical/pharmaceutical sector. For this sector, in fact, to a greater technical variety corresponds a greater use of preventive and predictive maintenance and also greater use of some modules of the CMMS ("spare parts purchasing management", "planning and scheduling of work orders" and "maintenance costs budgeting and reporting").

Some weak correlation has been noted also between the maintenance variables and the technical complexity (where an increasing technical complexity is observed, a certain tendency to adopt predictive maintenance and invest more time in the training is noted) and the interdependence (to an increasing interdependence corresponds a greater adoption of preventive maintenance policies, but not predictive).
At last, the equipments average age resulted another element strictly related to the maintenance variables: to a greater age of the equipments correspond a lower activity of preventive maintenance and a lower training of engineers, technicians and operators. This result is comprehensible because, especially in the paper sector, the authors has found situations with equipment older than 50 years, where the typologies of failure are well known and it is very hard to insert modern equipment to monitor all the parameters useful for the predictive maintenance.

Passing to the analysis of the correlations between the company characteristics variables and the implementation variables, a strong correlation between the company size (in terms of revenue and workforce) and the level of implementation of areas, software and information flows has been observed; in particular, the revenue appears to be the most significant element, especially for what concerns the whole sample. Comparing the two industrial sectors, it is observed that in the paper sector the main driver is the revenue, while in the chemical/pharmaceutical sector is the workforce. Revenue is positively correlated with the level of adoption of all the areas of the operational phase (especially with MEO and MMO), while in the design phase is correlated only with the MED area.
Differently than expected, for the chemical/pharmaceutical sector (and also for the paper sector) the correlations between the phases of the plant lifecycle that involve directly the company and the levels of implementation of areas, software and information flows resulted low significant. Perhaps this lack of significance can be attributed to the fact that the companies of this sector implement areas and flows regardless of the lifecycle directly managed. Limiting the study to the whole sample, it is possible, instead, to observe a positive correlation: the highest correlation coefficients are those in correspondence of the design and revamping phase.
Also the manufacturing strategy influences the levels of implementation of the areas: processes of continuous type are directly correlated with the levels of implementation of areas, software and flows, while small batch strategies does not favor this adoption. For the paper sector have not been identified significant correlations; this result probably can be attributed to the lower level of "maintenance culture" noted in this industrial sector.
In the analysis of technical variety, for the chemical/pharmaceutical sector has been observed a strong correlation with the level of implementation of the MEO, MMO, RCMO and SIO areas and software: greater is the presence of different assets in the production system and greater is the need of maintenance tools and methodology; the RCM area assumes particular importance in correspondence of a high variety of machines.
Technical complexity affects negatively some time needed to execute the maintenance tasks, as the time needed to restart the plant. Negative correlations with the implementation of areas, software and information flows were found, especially for the chemical/pharmaceutical sector and the whole sample.
From the perspective of the interdependence and equipments average age, few significant correlations were found.

To conclude the study of the third and fourth aims, the maintenance variables have been correlated with the implementation variables: the results show that the number of graduated

engineers, supervisors and maintenance technicians influences strongly and positively the level of implementation of areas, software and information flows. The qualified personnel, in fact, plays an important role in the introduction of new maintenance approaches and methodologies (the so-called "maintenance culture"). One of the major limitations to the implementation of these areas is in fact the lack of technical competences: in the chemical/pharmaceutical sector where the maintenance culture is higher than in the paper sector, is observed an higher level of implementation of areas, software and tools.
With regard to the possible correlations between the maintenance policies adopted and the levels of implementation, the results show that a greater propensity to adopt predictive maintenance approaches influence positively the levels of implementation of areas, software and information flows. On the other hand, a intensive use of corrective maintenance limits this implementation.
Passing to the correlations between the time spent for training on maintenance issues and the levels of implementation, positive and significant results are obtained only with the time of training spent on supervisors and maintenance technicians. No significant correlations were found with the training of graduated engineers: this can be easily explained considering that the graduated engineers often don't need training (because of their cultural background) and in some cases are the promoter of this training courses.
Finally, this work has showed strong positive correlations between the presence of specific modules of the CMMS and the levels of implementation: the computerization and the adoption of a big set of CMMS modules are necessary prerogatives for the implementation of areas, software and information flows.

Below is reported the table (presented before in the chapter 9) that summarizes the barriers and the success elements to the implementation of integrated solutions:

Table 118: barriers and success elements to the implementation of integrated solutions

	WHOLE SAMPLE	PAPER SECTOR	C/PH SECTOR
CATALYSTS	**Company size;** **Maintenance strategy (workforce);** **CMMS**; Human resource (training); Continuous type manufacturing strategy; Lifecycle; Technical variety.	**Company size;** **Maintenance strategy (workforce);** CMMS.	**Technical variety;** **maintenance strategy (workforce)**; CMMS; Human resource (training); Continuous type manufacturing strategy.
INIHIBITORS	Small batch type manufacturing strategy; Technical complexity.	Maintenance strategy (corrective maintenance).	Technical complexity; Small batch manufacturing strategy.

In conclusion it can be asserted that the main catalysts and, at the same time, inhibitors for the implementation of approaches, tools and methodology integrated along the plant lifecycle are two: the availability of economic resources and the maintenance culture of the company, intended as the degree of qualification and specialization of the maintenance personnel.

11.4 Fifth aim

The fifth aim has been studied to assess the potential interest of companies for a future implementation of integrated solutions. Considering only the design phase, the level of future implementation of areas is almost null. From the perspective of the operational phase, the situation still presents very low levels of future implementation, but higher than those of the design phase. Is observed a moderate interest by companies of the paper sector for the MEO area.
For the RPD, RPO, RCMO and DDR areas is not observed any future implementation of software. Software that present the highest values of implementation are those of the SIO, MEO and MMO areas (the most implemented areas).
The results concerning the future implementation of information flows show a more dynamic behavior of the paper companies, especially for those flows that involve the MEO and MMO areas. However, the interest is quite low.

To properly carry out considerations about the future implementations, it has been performed also a correlation analysis in order to observe if a future implementation of a specific area is correlated with the future implementation of a specific software or information flow. In this sense, positive and significant correlations have been found. The main drivers that lead the innovation are the areas: a modification to an area implies the modification of the related software; modifications to different areas and software imply the introduction or modification of the related information flow.

11.5 Final considerations concerning the two industrial sectors

The two industrial sector studied present different behaviors: the chemical/pharmaceutical companies show an higher level of implementation of areas, software and information flows, a superior level of knowledge, a greater integration of the maintenance activities along the plant lifecycle and, in general, an higher consistency between the manufacturing strategy adopted and the corresponding maintenance policies applied.
This better condition of the chemical/pharmaceutical companies is due to the following causes (in order of importance):

- Bigger company size, in terms of revenue and workforce: big revenues facilitate the introduction of very advanced activities, such as the RCM approach, that require skilled and dedicated personnel (these solutions need continuous investments and show their benefits only after several years). On the other hand, a qualified workforce, dedicated only to the maintenance activity, is the real first promoter for the introduction and the correct management of new maintenance solutions;
- The industrial sector: many companies that operate in the chemical/pharmaceutical sector are forced by special regulations to monitor the process and, above all, the product. This condition pushes the implementation of some maintenance tools and methodologies;

- The plant average age: some assets and equipments of the production process of the chemical/pharmaceutical companies require constant updating and replacement (to respect the quality standards fixed by the regulamentations), therefore the average age of the plant is lower than in the paper sector (and, as seen in the table 81, to a greater age of the equipments correspond a lower activity of preventive maintenance and a lower training of engineers, technicians and operators the age);
- A more international environment where the chemical/pharmaceutical companies operate: many companies of this sector belong to American and German multinationals, more inclined to the adoption of maintenance approaches, also advanced and sophisticated.

References

[1] Moubray J., 1997, *"Reliability-Centered Maintenance"*, London: Butterworth Heinemann.

[2] Gabbar H. A., Yamashita H., Suzuki K., Shimada Y., 2003. *"Computer-aided RCM-based plant maintenance management system"*, Elsevier, Robotics and Computer Integrated Manufacturing, 2003, vol.19, issue 5, pp. 449-458.

[3] Tucci M., Bettini G., 2006. *"Methods and tools for the Reliability Engineering: a plant maintenance perspective"*, Maintenance and Facility Management Conference, 27-28 Apr 2006 ,Sorrento, Italy.

[4] Huo, Z., Zhang, Z., Wang, Y., Yan, G., 2005. *"CMMS based reliability centered maintenance"*, IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China, 15-18 Aug 2005, pp. 1-6.

[7] Olszewski R., 2003, "*RCM success starts with CMMS*", CMMS data group inc., available on line: http://www.maintenanceworld.com/Articles/reliabilityweb/RCM_Success_CMMS.pdf

[8] Sikorska J., Hammond L., Kelly P., "*Identifying failure modes retrospectively using RCM data*", available on line: http://www.plant-maintenance.com/articles/Identifying_Failure_Modes.pdf

[9] Picknell, J. and Steel, KA, *"Using a CMMS to support RCM"*, Maintenance Technology, October, 110-117, 1997.

[10] Bandinelli, R.and Tucci, M. (2008) 'A Reference Model for the PLM Processes in Engineering and Contracting Sector', *PLM 2008, Fifth Conference on Product Lifecycle Management*, Seoul, Korea Jul 2008

[11] Schuman, C.A. and Brent A.C. (2005) 'Asset life cycle management: towards improving physical asset performance in the process industry' *The International Journal of Operations & Production Management* , Emerald, Vol. 25, No. 6, pp.566-579

[12] Forza C., 2002, "*Survey research in operations management: a process-based perspective*", International Journal of Operations & Production Management, Vol. 22 Iss: 2, pp.152 - 194

[13] Dubin, R., 1978, "Theory Building", the Free Press, New York, NY

[14] Malhotra, M.K. and Grover, V., 1998, "*An assessment of survey research in POM: from constructs to theory*", Journal of Operation Management, Vol.16 No.17, pp.407-25

[15] Wacker, J.G., 1998, "*A definition of theory: research guidelines for different theory-building research methods in operations management*", Journal of Operations Management, Vol.16 No.4, pp. 361-85.

[16] Barni L., Tucci M., Bonci L., Bettini G., 2009, "*Are RCM methodologies used along the plant lifecycle? Designing a survey*", 6th International Conference on Product Lifecycle Management, PLM09, 6-8 Jul 2009, Bath, UK

[17] Labib, A., W., 2004, *"A decision analysis model for maintenance policy selection using a CMMS"*, Journal of Quality in Maintenance Engineering, Emerald, 2004, vol. 10, number 3, pp. 191-202

[18] Barringer, P., 1996. "*Life Cycle Cost Tutorial*", avalaible on line: http://www.barringer1.com, 27 – 28.

[19] Blanchard, B.S. and Fabrycky, W.J. (1998) 'Systems Engineering and Analysis', *Prentice-Hall,* Upper Saddle River, NJ, pp. 19-29

[20] Marquez, A., C., Gupta, J., N., D., *"Contemporary maintenance management: process, framework and support pillars"*, Omega, Elsevier, 2006, vol. 34, n°3, pp. 313-326
[21] Morel G., Suhner M., Iung B. and Léger J.B., *"Maintenance holistic framework for optimising the cost/availability compromise of manufacturing systems"*, 6th IFAC Symposium on Cost Oriented Automation (Low Cost Automation 2001). Survey paper. Berlin, Germany, (2001) ISBN: 0-08-043907-1
[22] Marquez C. A, Gupta JND. *"Modern maintenance management forenhancing organizational efficiency"*. In: Gupta JND, Sharma S, editors. Intelligent enterprises ofthe 21st century. Hershey. USA: Idea Group Publishing; 2003. p.321–32.
[23] NASA Office for Safety and Mission Assurance, 2002, "*Fault Tree Handbook with Aerospace Applications*"
[24] USA Nuclear Regulatory Commission, 1981, "Fault Tree Handbook" NUREG 0492.
[25] Krasich M., 2000,. "*Use of Fault Tree Analysis for Evaluation of System-Reliability Improvements in Design Phase*" IEEE 2000 Proceedings Annual Reliability and Maintainability Symposium.
[26] Masdal S. I., Bye R., "*Integration of FTA and RCM - a case from shipping*".
[27] "*SAE JA1011, Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes*" (PDF). Society of Automotive Engineers. 01 AUG 1998.
[28] Fink A., Kosecoff J. 1985. "*How to conduct surveys. A step by step Guide*". Sage Publications.
[29] Alreck P., Settle R.B. 1985. "*The Survey Research Handbook*". Richard D.Irwin, Inc.
[30] Marczyk G., De Matteo D., Festinger D. 2005. "*Essentials of Research Design and Methodology*". John Wiley & Sons Inc.
[31] Porter, M.E., 1980, "*Competitive strategy*", Free Press, New York.
[32] Pinjala S. K., Pintelon L., Vereecke A., 2006, "*An empirical investigation on the relationship between business and maintenance strategies*", International Journal of Production Economics 104 214-229.
[33] Swanson, L., 1997, "*An empirical study of the relationship between production technology and maintenance management*", International Journal of Production Economics 53, 191-207.
[34] Krajeswski Lee J., Ritzman Larry P. (2002) "*Operations Management. Strategy and Analysis*", Prentice Hall.
[35] Gaither N., Fraizer G. (2002) "*Operation Management*", ninth ed. South-Western Thomson Learning USA.
[36] Kemppainen, K., Vepsäläinen, A.P.J. and Tinnilä M. (2008) "*Mapping the structural properties of production process and product mix*", International Journal of Production Economics Vol. 111, Issue 2 pp. 713-728.
[37] Ariss S., Zhang Q. (2002) "*The impact of flexible process capacity on the product – process matrix*", International Journal of Operation & Production Management Vol.22, pp. 103-124.
[38] Hayes, R., Wheelwright, S., 1984, "*Restoring our competitive edge, competiting through manufacturing*", Wiley Inc., New York.
[39] Hax, A.C., Majaluf, N.S., 1991, "*The strategy Concept and Process-A Pragmatic Approach*", Prentice-Hall International Inc., New Jersey.
[40] Fur*lanetto* L., Mastriforti C., 2002, "*Outsourcing e Global service. Nuova frontiera della manutenzione*", Edizioni FrancoAngeli.
[41] Perona M., Pistoni A., Pozzetti A., Tucci M. (2007) `*Riprogettare il servizio post-vendita*`, Edizioni Hoepli.

[42] Chandler, Alfred A., Jr., "*Strategy and Structure: Chapters in the History of American Industrial Enterprise*", The MIT Press, Cambridge, MA, 1962.

[43] Calinescu, A., Efstathiou, J., Sivadasan, S., Schirn, J. and Huaccho Huatuco, L. ,"*Complexity in Manufacturing: An Information Theoretic Approach*".

[44] Ilyukhin S.V., Haley T.A., Singh R.K., 2001. A survey of automation practices in the food industry. Food Control, 12, pp 285-296.

[45] Riis J., O., Luxhoj J.,Thorsteinsson U., 1997. "*A situational maintenance model*". International J. of Quality & Reliability Management. Vol. 14 No.4, p.349-366.

[46] Fedele L., Furlanetto L., Saccardi D.2004. "*Progettare e gestire la manutenzione*". Mc-Graw-Hill.

[47] Cooke, F.L. 2003. "*Plant maintenance strategy: Evidence from four British Manufacturing firms*". J. of Quality in Maintenance Engineering 9, 239-249.

[48] Hayes, R., Wheelwright, S., Clark K., 1988, "*Dynamic manufacturing: creating the learning organization*", Free Press New York.

[49] Kevin, F.G., Penlesky, R.J., 1988. "*A framework for developing maintenance strategies*". Production and Inventory Management Journal (First Quarter), 16–21.

[50] Skinner, W., 1969. "*Manufacturing—missing link in corporate strategy*". Harvard Business Review (May–June).

[51] Upshall P., 1991. "*Results of the Coopers & Lybrand and Works management UK Maintenance Survey*". Coopers & Lybrand, London.

[52] Jonsson P.,1997. "*The status of maintenance management in Swedish manufacturing firms*". J of Quality in Maintenance Engineering. Vol. 3 No.4, pp.233-258.

[53] Marshall Institute 1999. "*Maintenance effectiveness survey*". Marshall Institute, Inc. USA, available at: www.marshallinstitute.com/pvloz/mesurvey.pdf

[54] Benchmark Research & MCP Management 2000. "*The Maintenance Manager Survey 2000*".

[55] Tsang H.C.A., 2002, "*Strategic dimensions of maintenance management*", Journal of Quality in Maintenance Engineering 8 (1), 7-39.

[56] Furlanetto L. e al. 1998. "*Manuale di manutenzione degli impianti industriali e servizi*". FrancoAngeli.

[57] Niebel B.,W., 1985. "*Engineering Maintenance Management*". Marcel Dekker, Inc., New York.

[58] Kerlinger, F.N., 1986, "*Foundations of Behavioral Research*", 3rd ed., Harcourt Brace Jovanovich College Publishers, New York, NY.

[59] Carmines, E.G. and Zeller, R.A., 1990, "*Reliability and Validity Assesment*", Sage, New York, NY.

[60] Plant maintenance resource center, 2004. "*CMMS Implementation Survey*", available on line: http://www.plant-maintenance.com/articles/CMMS_survey_2004.shtml

[61] Plant maintenance resource center, 2007. "*RCM Implementation Survey*", available on line: http://www.plant-maintenance.com/cgi-bin/survey_RCM.cgi?action=VIEW&file base=RCM_survey

[62] Plant maintenance resource center, 1999. "*Design for Maintainability and Reliability: Survey Results*"

[63] Alsyouf I., 2007. "*Maintenance practices in Swedish industries: Survey results*", International Journal of Production Economics Volume 121, Issue 1, Pages 212-223.

[64] Mostafa S., 2004 "*Implementation of proactive maintenance in the Egyptian glass company*", Journal of Quality in Maintenance Engineering, Emerald, 2004, vol 10, number 2, pp. 107-122.

[65] Wireman T., 1990 "*World class maintenance management*", New York Industrial Press.
[66] Pintelon L.M., Gelders L.F., 1992 "*Maintenance Management decision making*", European Journal of Operation Research, 58:301-17.
[67] Lofall D. A., Mereckis T. A., "*Integrating CMMS with Predictive Maintenance Software*", http://www.dliengineering.com/downloads/integrating%20cmms.pdf

Appendix A

Questionnaire for companies that perform maintenance on their own plants

Advanced applications in maintenance: information flows

University of Florence
Department of Energy
“Sergio Stecco”

INTRODUCTION

Dear Sir/Madam,

this document is the questionnaire of a survey promoted and sponsored by the Department of Energy "Sergio Stecco" of the University of Florence (Faculty of Engineering).

AIM OF THE SURVEY

The utilization of software tools for assets and plant maintenance along their lifecycle represents a growing need for companies. Maintenance Engineering and Maintenance Management play an important role in reducing operative costs and improving performance and competitiveness.

Over the past thirty years, maintenance has changed, perhaps more than any other management discipline. Many factors have promoted these change: the increase in the number and variety of physical assets (service plants, equipments and buildings), much more complex designs, new maintenance techniques and so on. This context has required first the coming out of new maintenance methodologies and techniques, then their computerization and automation by means of specific tools. Today several methodologies are available in order to study, model, assess and optimize asset reliability.

Starting from these bases and passing through the definition of the company structural variables (productive context, business and maintenance strategies adopted, Reliability & Maintenance Engineering areas implemented, related informative flows and so on), this survey aims at assessing:

- the current level of knowledge, automation and implementation in companies of integrated tools and methodologies in maintenance, special purpose software and information flow
- the potential interest in industry for a future implementation of integrated solutions.

BENEFITS FOR COMPANIES INTERVIEWED

Companies interviewed will receive indications about their degree of maturity on the issues proposed and their positioning on the global context. This survey will represent a benchmarking, an useful process of comparing the maintenance approach adopted by the company interviewed to the best practices adopted by the 'best in class'.

PRIVACY

Information provided by companies interviewed will be used only for statistical analysis and not for advertising. All data and all information will not given to other companies or competitors.

PERSON INTERVIEWED

Suname:____

Name:____

Position in the Company:____

Telephone number:____

E-mail:____

□ The participation of the Company at this survey will be not mentioned.

GENERAL INFORMATION ABOUT COMPANY

1. **Company Name:**

____

2. Registered Office:

Street:____ n°_______________

City:___________________________________ZIP code:_____________________

Web site:____

3. Revenue 2007 (€):

- □ <500.000
- □ 500.000-2.500.000
- □ 2.500.000-5.000.000
- □ 5.000.000-25.000.000
- □ 25.000.000-50.000.000
- □ 50.000.000-250.000.000
- □ 250.000.000-500.000.000
- □ >500.000.000

4. Workforce 2007:

- □ <5
- □ 5-25
- □ 25-50
- □ 50-250
- □ 250-500
- □ 500-2500
- □ 2500-5000
- □ >5000

5. Companies whose you are Owner (O) or Dealership (D):

___________________________ [O] [D] ___________________________ [O] [D]

___________________________ [O] [D] ___________________________ [O] [D]

6. Group Affiliation:

Group name:____

7. Indicate the type of your industry[1]:

- Mfr. of food products and tobacco products;
- Mfr. of textiles;
- Mfr. of wood and wood products;
- Mfr. of pulp, paper and paper products;
- Mfr. of chemical raw materials and Mfr. of rubber and plastic products;
- Mfr. of tiles, bricks, cement and concrete (and other minerals, not metals);
- Mfr. of metal products;
- Distribution of electricity, gas and water;
- Mfr. of building materials;
- Production of electricity;
- Other (specify):____

8. Indicate the type of plants operated and the stages of their lifecycle that involve directly your company:

Design	**Construction**	**Operation**	**Revamping**

***9.* Plants that you maintain are subjected to special regulations (i.e. fire risk)**

____

____

____

1 Industrial classification in accordance with NACE/DB03.
NACE: Nomenclature generale des Activitiés économique dans les Communautes Européennes

10. Which of these business strategies is your company adopting?

- □ Cost leadership strategy: by producing high volumes of standardized products, the firm hopes to take advantage of economies of scale and experience curve effects. The product is often a basic no-frills product that is produced at a relatively low cost and made available to a very large customer base.
- □ Differentiation strategy: the company distinguishes itself by its:
  - o Innovation
  - o Service level
  - o Quality
  - o Performance
  - o Other (specify):___________________
- □ Market segmentation strategy
- □ Other (specify):______________________

CHARACTERISTICS OF PRODUCTION TECHNOLOGY

11. Manufacturing Strategy: specify the degree of adoption, on your plants, of the following production categories:

	Do not have	Used minimally		Used moderately		Used extensively
Job shop technology: production of single or small quantities of a large number of different products, according to direct specifications of the customer.	0	1	2	3	4	5
Small batch technology: production of small batches with large variety.	0	1	2	3	4	5
Large batch – Line technology: production of large batches and low variety.	0	1	2	3	4	5
Continuous process technology: production of huge volumes of a single product or a very limited range of products.	0	1	2	3	4	5

12. Technical variety: how would you characterize equipment in your plants along the following dimensions?:

a single type of production equipment represent more than 80% of total plant production equipments	1	2	3	4	5	no single type of equipment represents more than 20%
the production equipments are supplied by few OEM'S[2]	1	2	3	4	5	the production equipments are supplied by many different OEM'S
the production equipments are standard	1	2	3	4	5	the production equipments are customized

[2] OEM = Original Equipment Manufacturer

13. Technical variety: quantify the frequency (from very low to very high) of different types of failures (recurrent, intermittent, unusual) that occur on the equipments of your plants.

Recurrent failure	o Very low o Low o Medium o High o Very high
Intermittent failure	o Very low o Low o Medium o High o Very high
Unusual failure	o Very low o Low o Medium o High o Very high

14. Technical complexity: On average, how many time do you need to identify a failure, to prepare the intervention, to repair the failure and to put back in working order the plant?

time for identifying the failure	Tempo for preparing the intervention	Temp for repairing the failure	time for restarting the plant
o Very low o Low o Medium o High o Very high	o Very low o Low o Medium o High o Very high	o Very low o Low o Medium o High o Very high	o Very low o Low o Medium o High o Very high

15. Technical complexity: indicate the percentage of machines that implement flexible integrated automation (Flexible Manufacturing Systems, Flexible Assembly Systems, Flexible Manufacturing Line, Flexible Manufacturing Cell, Automatic Transfer Line, Numeric Control).

____

____

16. Interdependence: how would you characterize conditions in your plant for each of the following dimensions?

No buffer stocks between the phases of the production process	1	2	3	4	5	Buffer stocks between all the phases of the production process
If a breakdown occurs, no re-routing of work is possible	1	2	3	4	5	If a breakdown occurs, work is easily rerouted through the plant
Rigid production flow	1	2	3	4	5	No rigid production flow

17. Interdependence: if a breakdown of a singular machine occurs, the production process can stop totally or continue without problem. Indicate the percentage of the production process phases that stop within the first hour of a singular machine breakdown:

- 0 to 20%
- 21 to 40%
- 41 to 60%
- 61 to 80%
- 81 to 100%

***18.* Age of equipments: could you give an age-group classification (in percentage) of equipments installed?**

Equipments [percentage]	Age [years]
	0-2
	3-5
	6-10
	11-20
	21-40
	Over 40

MAINTENANCE STRATEGY

19. Vertical integration of maintenance*:* how maintenance is performed?

- totally outsourced (Global Service contracts or Global Service at life cycle cost contracts). Indicate the type of outsourcer:
  - Captive
  - Market
- partially outsourced, with maintenance engineering and management in house. Indicate the percentage of maintenance activities outsourced________________
- In house.
- Other (specify):____________ ____

20. Maintenance organization: (*only if maintenance is performed in house or partially out-sourced)* **the maintenance is a business function of the company?**

- Yes. Specify the annual budget

  ____

- No. Specify within business operation maintenance function is contained

  ____

  ____

21. Maintenance organization: how is organized the structure of maintenance in your company?

- Centralized
- Mixed
- De-centralized

22. Maintenance organization and capacity: is there in your company a distinction among Maintenance Management and Maintenance Engineering?

- o Yes. specify the number of workers in the Maintenance Management area and Maintenance Engineering area:

	Number of workers in the Maintenance Engineering area	Number of workers in the Maintenance Management area
Graduated engineers		
Supervisors		
Technicians		

- o No. specify the total number of workers in the Maintenance area:

	Number of workers
Graduated engineers	
Supervisors	
Technicians	

21bis. Maintenance policies: specify, in relation to the total number of maintenance interventions on the equipments, the percentage of actions of corrective, preventive and predictive maintenance:

Corrective Maintenance	o Low (<30%) o Medium (30-45%) o High (>45%)
Preventive Maintenance	o Low (<30%) o Medium (30-45%) o High (>45%)
Predictive Maintenance	o No performed o Low (<20%) o High (>20%)

22bis Maintenance policies: (*only if company designs its plants*) **your plant designers are adopting DFR/DFA (design for reliability/availability) techniques?**

- o Yes
- o No
  - o We don't have them but we consider them important
  - o We don't have them and we don't consider them important

23. Maintenance planning and control systems: have your company adopted a CMMS (Computerized Maintenance Management System) system?

o **INTEGRATED (ERP module)**

YES	✓ Software: o SAP o NAVISION o ORACLE o Software customized. Name:_________________________ o Other. Name:____ ✓ Modules contained in the ERP adopted: □ Finance □ Controlling □ Treasuring □ Project System □ Production Planning □ Plant Maintenance □ Sales & Distribution □ Human Resources □ Material Management □ Quality Management
NO	o our company is not ready for its implementation o too expensive, but we consider it strategic for our company o not strategic for our company o our company has a Stand – Alone software

o **STAND ALONE**

YES	✓ Software: o MAXIMO o DATASTREAM o Software customized. Name:_________________________ o Other. Name:_________________________
NO	o our company is not ready for its implementation o too expensive, but we consider it strategic for our company o not strategic for our company o our company has an ERP

24. Maintenance planning and control systems: if a CMMS is implemented, specify in which activities it is employed	
□ Planning and scheduling of work orders	o Never o Rarely o Frequently o Systematically
□ Planning of maintenance activities (preventive and predictive)	o Never o Rarely o Frequently o Systematically
□ Data recording of works performed	o Never o Rarely o Frequently o Systematically
□ Spare parts management (inventory)	o Never o Rarely o Frequently o Systematically
□ Spare parts management (purchasing)	o Never o Rarely o Frequently o Systematically
□ Maintenance workforce management	o Never o Rarely o Frequently o Systematically
□ Maintenance costs budgeting and re-porting	o Never o Rarely o Frequently o Systematically
□ Data reporting of maintenance works performer	o Never o Rarely o Frequently o Systematically
□ Data base for availability/reliability analysis	o Never o Rarely o Frequently o Systematically
□ Data base for the optimization of the maintenance policies	o Never o Rarely o Frequently o Systematically
□ Data base for the redesign of compo-nents or equipments	o Never o Rarely o Frequently o Systematically

24bis Human resources: specify the average time spent for training on issues of maintenance

Graduated engineers	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Supervisors	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Technicians	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Production operators	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year

25. Human resources: specify the degree of involvement of production operators in maintenance activities

Routine repairing	o Low o Medium o High
Resettlement of simple breakdowns	o Low o Medium o High
Works of preventive maintenance	o Low o Medium o High
Works of predictive maintenance	o Low o Medium o High

IMPLEMENTATION OF MAINTENANCE TOOLS AND METHODOLOGY, THEIR INTEGRATION AND RELATED INFRMATION FLOW ADOPTION

26. Referring to the model map enclosed and to the RME PROCESS AREAS TABLE (Reliability, Maintenance, Engineering), specify the areas employed

27. **Identify the methodologies implemented in your company for each RME process area**

- □ FTA/D
- □ ETA/D
- □ FMECA/D
- □ RBD/D
- □ HAZOP/D
- □ FTA/O
- □ ETA/O
- □ FMECA/O
- □ RBD/O
- □ HAZOP/O

29. Referring to the model map enclosed and to the RME SOFTWARE TOOLS TABLE - PRESENT, specify for each RME process area if a specialized software is implemented, specify its name and the rate of its utilization

30. Referring to the model map enclosed and to the RME SOFTWARE TOOLS TABLE - FUTURE, specify for each RME process area if a specialized software will be implemented and specify its name

31. Referring to the model map enclosed and to the INFORMATION FLOW TABLE, specify the presence of the information flows adopted (to link the different RME process areas), their typology (if automated or manual) and the flow rate of information exchange

Advanced applications in maintenance: information flow – RME Process Areas Table

University of Florence
Department of Energy
“Sergio Stecco”

RME PROCESS AREAS				
RME Process Areas	Current level of implementation	Importance perceived	Future implementation (if not implemented at the moment)	Potential importance
RPD	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
MED	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
RCMD	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
DDD	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
MEO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5

RME PROCESS AREAS				
RME Process Areas	Current level of implementation	Importance perceived	Future implementation (if not implemented at the moment)	Potential importance
RPO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
RCMO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
SIO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
MMO	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5
DDR	o Not present o Limited o Significant o Complete	o 1 o 2 o 3 o 4 o 5	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3-5 years) o Planned in long period (more than 5 years)	o 1 o 2 o 3 o 4 o 5

Advanced applications in maintenance: information flows

University of Florence
Department of Energy
“Sergio Stecco”

RME Software Tools Table - Present			
RME Process Areas	Software implemented and utilization rate		Importance perceived
RPD	o Not present o Limited utili-zation o Significant utilization o Systematic utilization	Name: ✓ ____ ✓ ____ ✓ ____	o 1 o 2 o 3 o 4 o 5
MED	o Not present o Limited utili-zation o Significant utilization o Systematic utilization	Name: ✓ ____ ✓ ____ ✓ ____	o 1 o 2 o 3 o 4 o 5
RCMD	o Not present o Limited utili-zation o Significant utilization o Systematic utilization	Name: ✓ ____ ✓ ____ ✓ ____	o 1 o 2 o 3 o 4 o 5
DDD	o Not present o Limited utili-zation o Significant utilization o Systematic utilization	Name: ✓ ____ ✓ ____ ✓ ____	o 1 o 2 o 3 o 4 o 5
MEO	o Not present o Limited utili-zation o Significant utilization o Systematic utilization	Name: ✓ ____ ✓ ____ ✓ ____	o 1 o 2 o 3 o 4 o 5

RME Software Tools Table - Present			
RME Process Areas	Software implemented and utilization rate		Importance perceived
RPO	o Not present	Name:	o 1 o 2 o 3 o 4 o 5
	o Limited utilization o Significant utilization o Systematic utilization	✓ __________ ✓ __________ ✓ __________	
RCMO	o Not present	Name:	o 1 o 2 o 3 o 4 o 5
	o Limited utilization o Significant utilization o Systematic utilization	✓ __________ ✓ __________ ✓ __________	
SIO	o Not present	Name:	o 1 o 2 o 3 o 4 o 5
	o Limited utilization o Significant utilization o Systematic utilization	✓ __________ ✓ __________ ✓ __________	
MMO	o Not present	Name:	o 1 o 2 o 3 o 4 o 5
	o Limited utilization o Significant utilization o Systematic utilization	✓ __________ ✓ __________ ✓ __________	
DDR	o Not present	Name:	o 1 o 2 o 3 o 4 o 5
	o Limited utilization o Significant utilization o Systematic utilization	✓ __________ ✓ __________ ✓ __________	

Advanced applications in maintenance: information flows

University of Florence
Department of Energetics
“Sergio Stecco”

<table>
<tr><th colspan="4">RME Software Tools Table - Future</th></tr>
<tr><th>RME Process Areas</th><th colspan="2">Planned implementation</th><th>Potential importance</th></tr>
<tr><td rowspan="2">RPD</td><td>o Not planned</td><td>Name:</td><td rowspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
<tr><td>o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td><td>✓ ____________
✓ ____________
✓ ____________</td></tr>
<tr><td rowspan="2">MED</td><td>o Not planned</td><td>Name:</td><td rowspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
<tr><td>o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td><td>✓ ____________
✓ ____________
✓ ____________</td></tr>
<tr><td rowspan="2">RCMD</td><td>o Not planned</td><td>Name:</td><td rowspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
<tr><td>o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td><td>✓ ____________
✓ ____________
✓ ____________</td></tr>
<tr><td rowspan="2">DDD</td><td>o Not planned</td><td>Name:</td><td rowspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
<tr><td>o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td><td>✓ ____________
✓ ____________
✓ ____________</td></tr>
<tr><td rowspan="2">MEO</td><td>o Not planned</td><td>Name:</td><td rowspan="2">o 1
o 2
o 3
o 4
o 5</td></tr>
<tr><td>o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td><td>✓ ____________
✓ ____________
✓ ____________</td></tr>
</table>

RME Software Tools Table - Future			
RME Process Areas	Planned implementation		Potential importance
RPO	o Not planned	Name:	o 1 o 2 o 3 o 4 o 5
	o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	✓ ____________ ✓ ____________ ✓ ____________	
RCMO	o Not planned	Name:	o 1 o 2 o 3 o 4 o 5
	o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	✓ ____________ ✓ ____________ ✓ ____________	
SIO	o Not planned	Name:	o 1 o 2 o 3 o 4 o 5
	o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	✓ ____________ ✓ ____________ ✓ ____________	
MMO	o Not planned	Name:	o 1 o 2 o 3 o 4 o 5
	o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	✓ ____________ ✓ ____________ ✓ ____________	
DDR	o Not planned	Name:	o 1 o 2 o 3 o 4 o 5
	o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)	✓ ____________ ✓ ____________ ✓ ____________	

Advanced applications in maintenance: information flows – Information Flows Table

20

University of Florence
Department of Energetics
“Sergio Stecco”

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">RPD-MED</td><td>Level of implementa-
tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">MED-DDD</td><td>Level of implementation</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually inter-changed between data bases
o Automated realign-ment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an auto-mated information ex-change</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">DDD-MED</td><td>Level of imple-mentation</td><td>Typology of communication</td><td>Flow rate of information ex-change</td></tr>
<tr><td>o Not present
o Limited
o Signifi-cant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance per-ceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">MED-RCMD</td><td>Level of imple-mentation</td><td>Typology of communication</td><td>Flow rate of information ex-change</td></tr>
<tr><td>o Not present
o Limited
o Signifi-cant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance per-ceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

Design Stage	Current Level of Implementation		
RCMD-DDD	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Design Stage	Current Level of Implementation		
DDD-CBD	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of da-ta bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Design Stage	Current Level of Implementation		
DDD-DD	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Design Stage	Current Level of Implementation		
DDD-C	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">C-DDD</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of da-ta bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">MED-MEO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of da-ta bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">DDD-MEO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of da-ta bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">DDD-MMO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of da-ta bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Design Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="6">DDD-DDR</td><td>Level of implementation</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Operation Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="6">MEO-MMO</td><td>Level of implementation</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Operation Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">MMO-MEO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Operation Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="7">MEO-RCMO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

Operation Stage	Current Level of Implementation		
RCMO-MMO	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MMO-RCMO	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MMO-RPO	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
RPO-MEO	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

<table>
<tr><td>Operation Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="6">SIO-MMO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

<table>
<tr><td>Operation Stage</td><td colspan="3">Current Level of Implementation</td></tr>
<tr><td rowspan="6">SIO-RPO</td><td>Level of implementa-tion</td><td>Typology of communication</td><td>Flow rate of information exchange</td></tr>
<tr><td>o Not present
o Limited
o Significant
o Complete</td><td>o Manual data transfer
o Files manually interchanged between data bases
o Automated realignment of data bases
o Integrated Data Base</td><td>How many loops?</td></tr>
<tr><td colspan="3">Future implementation</td></tr>
<tr><td colspan="3">o Not planned
o Planned in short period (within 1-2 years)
o Planned in medium period (within 3 years)
o Planned in long period (more than 3 years)</td></tr>
<tr><td>Importance perceived</td><td>Potential importance</td><td>Interest for an automated information exchange</td></tr>
<tr><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td><td>o 1
o 2
o 3
o 4
o 5</td></tr>
</table>

Operation Stage	Current Level of Implementation		
SIO-MEO	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MMO-DDR	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
SIO-MNT/OP	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MNT/OP-SIO	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MMO-MNT/OP	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Operation Stage	Current Level of Implementation		
MNT/OP-MMO	Level of implementa-tion	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Revamping Stage	Current Level of Implementation		
DDR-RVP	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Revamping Stage	Current Level of Implementation		
RVP-DDR	Level of implementation	Typology of communication	Flow rate of information exchange
	o Not present o Limited o Significant o Complete	o Manual data transfer o Files manually interchanged between data bases o Automated realignment of data bases o Integrated Data Base	How many loops?
	Future implementation		
	o Not planned o Planned in short period (within 1-2 years) o Planned in medium period (within 3 years) o Planned in long period (more than 3 years)		
	Importance perceived	Potential importance	Interest for an automated information exchange
	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5	o 1 o 2 o 3 o 4 o 5

Appendix B

Questionnaire for companies that perform maintenance on third parties' plants

Advanced applications in

...rmation

flows

University of Florence
Department of Energetics "Sergio Stecco"

INTRODUCTION

Dear Sir/Madam,

this document is the questionnaire of a survey promoted and sponsored by the Department of Energy “Sergio Stecco” of the University of Florence (Faculty of Engineering).

AIM OF THE SURVEY

The utilization of software tools for assets and plant maintenance along their lifecycle represents a growing need for companies. Maintenance Engineering and Maintenance Management play an important role in reducing operative costs and improving performance and competitiveness.

Over the past thirty years, maintenance has changed, perhaps more than any other management discipline. Many factors have promoted these change: the increase in the number and variety of physical assets (service plants, equipments and buildings), much more complex designs, new maintenance techniques and so on. This context has required first the coming out of new maintenance methodologies and techniques, then their computerization and automation by means of specific tools. Today several methodologies are available in order to study, model, assess and optimize asset reliability.

Starting from these bases and passing through the definition of the company structural variables (productive context, business and maintenance strategies adopted, Reliability & Maintenance Engineering areas implemented, related informative flows and so on), this survey aims at assessing:

- the current level of knowledge, automation and implementation in companies of integrated tools and methodologies in maintenance, special purpose software and information flow
- the potential interest in industry for a future implementation of integrated solutions.

BENEFITS FOR COMPANIES INTERVIEWED

Companies interviewed will receive indications about their degree of maturity on the issues proposed and their positioning on the global context. This survey will represent a benchmarking, an useful process of comparing the maintenance approach adopted by the company interviewed to the best practices adopted by the ‘best in class’.

PRIVACY

Information provided by companies interviewed will be used only for statistical analysis and not for advertising. All data and all information will not given to other companies or competitors.

PERSON INTERVIEWED

Surname:____

Name:____

Position in the Company:____________ ____________________________________

Telephone number:_____________________ _______________________________

E-mail:____

□ The participation of the Company at this survey will be not mentioned.

GENERAL INFORMATION ABOUT COMPANY

2. **Company Name:**

____

11. Registered Office:

Street:____ n°________________

City:__________ _____________________ZIP code:_______________________________

Web Site:__________ ____

12. Revenue 2007 (€):

□ <500.000
□ 500.000-2.500.000
□ 2.500.000-5.000.000
□ 5.000.000-25.000.000
□ 25.000.000-50.000.000
□ 50.000.000-250.000.000
□ 250.000.000-500.000.000
□ >500.000.000

13. Workforce 2007:

□ <5
□ 5-25
□ 25-50
□ 50-250
□ 250-500
□ 500-2500
□ 2500-5000
□ >5000

14. Indicate in percentage the typology of companies, your customers[3]:

Typology	Percentage
Mfr. of food products and tobacco products;	
Mfr. of textiles;	
Mfr. of wood and wood products;	
Mfr. of pulp, paper and paper products;	
Mfr. of chemical raw materials and Mfr. of rubber and plastic products;	
Mfr. of tiles, bricks, cement and concrete (and other minerals, not metals);	
Mfr. of metal products;	
Distribution of electricity, gas and water;	
Mfr. of building materials;	
Production of electricity;	
Other (specify):___________________________	

5. Indicate the typology of services offered by your Company[4]:

□ Plant Designing
Specify the percentage of services of this typology performed per year ____

□ Engineering & Contracting and Plant Construction
Specify the percentage of services of this typology performed per year ____

□ Operational services with clearly-defined responsibilities: services that involve responsibility of the service provider limited to the effectiveness of individual commitments. These activities generally are scheduled and end with the testing of works performed by service provider. Usually the contract for this kind of services exclude a "thinking" involvement of the service provider. Examples are the operations of corrective maintenance.
Specify the percentage of services of this typology performed per year ____

□ Maintenance engineering and management services: include commitments generally placed in the maintenance engineering and management. Examples are the realization of inspection plans, price lists, tenders, maintenance plans and so on.
Specify the percentage of services of this typology performed per year ____

[3] Industrial classification in accordance with NACE/DB03.
NACE: Nomenclature generale des Activitiés économique dans les Communautes Européennes
[4] Classification suggested by Furlanetto "Outsourcing e Global Service"

- □ Maintenance global service: contract for turnkey maintenance services with full responsibility of the service provider.
  Specify the percentage of services of this typology performed per year ____

- □ Maintenance global service at life cycle cost: this contract involves the purchase of "productive functionality" of a technological apparatus along a wide span of time. Examples of "productive functionality" are the plant availability, the production volume and so on.
  Specify the percentage of services of this typology performed per year ____

- □ Consulting
  - □ Organization advice
  - □ Technical advice
  - □ Training

  Specify the percentage of services of this typology performed per year ____

***6.* Does your Company offer services also to industries with plants subjected to special regulations (i.e. fire risk)?**

____

____

____

7. Which of these business strategies is your company adopting?

- □ Cost leadership strategy: by producing high volumes of standardized products, the firm hopes to take advantage of economies of scale and experience curve effects. The product is often a basic no-frills product that is produced at a relatively low cost and made available to a very large customer base.
- □ Differentiation strategy: the company distinguishes itself by its:
  - o Innovation
  - o Service level
  - o Quality
  - o Performance
  - o Other (specify):___________________
- □ Market segmentation strategy
- □ Other (specify):______________________

COMPANY ORGANIZATION

8. Specify the legal form of your company

- o Independent Business Unit of a big Company with its profit and loss account;
- o Autonomous Company.

9. Specify the internal articulation of your Company

- o By geographical area
- o By type of customer
- o By type of service provided
- o By industrial sector served
- o Other (specify):____

10. Do you displace staff to your customers?

- o No
- o Yes. How many people?

Staff	Number
Graduated engineers	
Supervisors	
Technicians	

Maintenance strategy

24. Maintenance organization and capacity: is there in your company a distinction among Maintenance Management and Maintenance Engineering?

- o Yes. specify the number of workers in the Maintenance Management area and Maintenance Engineering area:

	Number of workers in the Maintenance Engineering area	Number of workers in the Maintenance Management area
Graduated engineers		
Supervisors		
Technicians		

- o No. specify the total number of workers in the Maintenance area:

	Number of workers
Graduated engineers	
Supervisors	
Technicians	

12 Maintenance policies: specify, in relation to the total number of maintenance interventions on the equipments of your customers, the percentage of actions of corrective, preventive and predictive maintenance:	
Corrective Maintenance	o Low (<30%) o Medium (30-45%) o High (>45%)
Preventive Maintenance	o Low (<30%) o Medium (30-45%) o High (>45%)
Predictive Maintenance	o No performed o Low (<20%) o High (>20%)

13 Maintenance policies: your plant designers are adopting DFR/DFA (design for reliability/availability) techniques?

o Yes	
o No	o We don’t have them but we consider them important o We don’t have them and we don’t consider them important

Maintenance planning and control systems: have your company adopted a CMMS (Computerized Maintenance Management System) system?

- **INTEGRATED (ERP module)**

YES	✓ Software: o SAP o NAVISION o ORACLE o Software customized. Name:__________________________ o Other. Name:____ ✓ Modules contained in the ERP adopted: □ Finance □ Controlling □ Treasuring □ Project System □ Production Planning □ Plant Maintenance □ Sales & Distribution □ Human Resources □ Material Management □ Quality Management
NO	o our company is not ready for its implementation o too expensive, but we consider it strategic for our company o not strategic for our company o our company has a Stand – Alone software

- **STAND ALONE**

YES	✓ Software: o MAXIMO o DATASTREAM o Software customized. Name:__________________________ o Other. Name:__________________________
NO	o our company is not ready for its implementation o too expensive, but we consider it strategic for our company o not strategic for our company o our company has an ERP

28. Maintenance planning and control systems: if a CMMS is implemented, specify in which activities it is employed[5]	
□ Planning and scheduling of work orders	o Never o Rarely o Frequently o Systematically
□ Planning of maintenance activities (preventive and predictive)	o Never o Rarely o Frequently o Systematically
□ Data recording of works performed	o Never o Rarely o Frequently o Systematically
□ Spare parts management (inventory)	o Never o Rarely o Frequently o Systematically
□ Spare parts management (purchasing)	o Never o Rarely o Frequently o Systematically
□ Maintenance workforce management	o Never o Rarely o Frequently o Systematically
□ Maintenance costs budgeting and reporting	o Never o Rarely o Frequently o Systematically
□ Data reporting of maintenance works performer	o Never o Rarely o Frequently o Systematically
□ Data base for availability/reliability analysis	o Never o Rarely o Frequently o Systematically
□ Data base for the optimization of the maintenance policies	o Never o Rarely o Frequently o Systematically
□ Data base for the redesign of components or equipments	o Never o Rarely o Frequently o Systematically

[5] Activities of CMMS suggested by Pinjala, Pintelon and Vereecke: "An empirical investigation on the relationship between business and maintenance strategies"

21. Human resources: specify the average time spent for training on issues of maintenance

Graduated engineers	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Supervisors	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Technicians	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year
Production operators	o Less than 20 hours per year o 20 to 39 hours per year o 40 to 59 hours per year o 60 to 79 hours per year o More than 80 hours per year

22. Human resources: specify the degree of involvement of production operators in maintenance activities that your Company provides

Routine repairing	o Low o Medium o High
Resettlement of simple breakdowns	o Low o Medium o High
Works of preventive maintenance	o Low o Medium o High
Works of predictive maintenance	o Low o Medium o High

IMPLEMENTATION OF MAINTENANCE TOOLS AND METHODOLOGY, THEIR INTEGRATION AND RELATED INFRMATION FLOW ADOPTION

23. Referring to the model map enclosed and to the RME PROCESS AREAS TABLE (Reliability, Maintenance, Engineering), specify the areas employed

24. **Identify the methodologies implemented in your company for each RME process area**

- □ FTA/D
- □ ETA/D
- □ FMECA/D
- □ RBD/D
- □ HAZOP/D
- □ FTA/O
- □ ETA/O
- □ FMECA/O
- □ RBD/O
- □ HAZOP/O

25. Referring to the model map enclosed and to the RME SOFTWARE TOOLS TABLE - PRESENT, specify for each RME process area if a specialized software is implemented, specify its name and the rate of its utilization

26. Referring to the model map enclosed and to the RME SOFTWARE TOOLS TABLE - FUTURE, specify for each RME process area if a specialized software will be implemented and specify its name

27. Referring to the model map enclosed and to the INFORMATION FLOW TABLE, specify the presence of the information flows adopted (to link the different RME process areas), their typology (if automated or manual) and the flow rate of information exchange