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MATURITY ASSESSMENT OF PHYSICAL ASSET MANAGEMENT PRACTICES IN MANUFACTURING PLANTS AND INFRASTRUCTURES

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Abstract

As a consequence of the increasingly open global competitive environment caused by the higher pressure to reduce costs, to increase profit margins and, last but not least, to integrate the concepts of sustainable development in the business strategy, a different and broader vision of maintenance, extended throughout the life cycle of the *assets* and all the processes involved, has been developed. This approach, called *Physical Asset Management* (PAM), has shown important innovations and relevant changes in the maintenance management methods, especially in *asset intensive* companies such as those dealing with infrastructures and public utilities networks.

This Master of Science thesis work aims at developing and testing a model for the maturity assessment of PAM practices, to be applied across different industrial sectors, having as target the field of manufacturing plants, services networks and infrastructures (such as water, energy, gas, railway infrastructure,..).

From a methodological perspective, the work aims at studying the potentiality of pre-existent *maturity assessment* approaches. In particular, two approaches were mainly considered. The former is the result of the research activities carried out in the frame of *TeSeM Observatory* (on Technologies and Services for Maintenance) of the *School of Management* of Politecnico di Milano, and focuses on maintenance aspects such as the information systems, the technologies for Condition Based Maintenance, and the development of strategy through maintenance policies. The latter is developed by a research group at University of Technology of Delft (TUDelft), *Faculty of Technology, Policy and Management*, and studies the PAM practices at different levels of decision making (operational, tactical and strategic); the practices particularly focused by the TUDelft concern long term investment decisions, lifecycle approach, risk management, organizational culture and leadership. The model proposed in this work adapts these pre-existent methodologies of maturity assessment, thus developing a new model for the maturity assessment of PAM practices. As a result of the thesis, the theoretical concepts are tested by means of analysis of three real case studies in The Netherlands in the infrastructure sector, and of two real case studies in Italy in the manufacturing sector.

Abstract

Come conseguenza del sempre più aperto e competitivo ambiente globale causato dalla maggiore pressione per ridurre i costi, aumentare i margini di profitto e, ultimo ma non meno importante, per integrare i concetti di sviluppo sostenibile nella strategia di business, una diversa e più ampia visione di manutenzione, estesa a tutto il ciclo di vita degli *assets* e di tutti i processi coinvolti, è stata sviluppata. Questo approccio, chiamato Physical Asset Management (PAM), ha mostrato importanti novità e cambiamenti rilevanti nei metodi di gestione della manutenzione, soprattutto in aziende *asset intensive*, come quelle che si occupano di infrastrutture e di reti di *public utilities*.

Il lavoro di Tesi mira a sviluppare e testare un modello per la valutazione delle pratiche di maturità PAM, da applicare nei diversi settori industriali, quali impianti di produzione, reti di servizi e infrastrutture (ad esempio, acqua, energia, gas , infrastruttura ferroviaria, ..).

Dal punto di vista metodologico, il lavoro si propone di studiare la potenzialità di approcci scadenza pre-esistenti di valutazione. In particolare, due approcci sono stati principalmente considerati. Il primo è il risultato delle attività di ricerca svolte nell'ambito dell'Osservatorio del TeSeM (su Tecnologie e Servizi per la manutenzione) della *School of Management* del Politecnico di Milano, e si concentra su aspetti di gestione della manutenzione, come i sistemi di informazione, le tecnologie per la manutenzione su condizione, e lo sviluppo della strategia attraverso politiche di manutenzione. Il secondo è sviluppato da un gruppo di ricerca presso la *University of Technology* di Delft (TUDelft), *Faculty of Technoloy, Policy and Management*, e studia le pratiche PAM a diversi livelli del processo decisionale (operativo, tattico e strategico); le pratiche approfondite dalla TUDelft riguardano decisioni di investimento a lungo termine, l'approccio del ciclo di vita, gestione dei rischi, la cultura organizzativa e di leadership. Il modello proposto in questo lavoro adatta queste pre-esistenti metodologie di valutazione della maturità, sviluppando un nuovo modello per la valutazione delle pratiche di maturità PAM. Come risultato della tesi, i concetti teorici sono testati attraverso l'analisi di tre casi reali nei Paesi Bassi nel settore delle infrastrutture, e di due casi reali in Italia nel settore manifatturiero.

Executive Summary

What is Physical Asset Management?

As a consequence of the increasingly open global competitive environment caused by the higher pressure to reduce costs, increase profit margins and, last but not least, integrate the concepts of sustainable development in the business strategy, a different and broader vision of maintenance, extended throughout the life cycle of the *assets* and all the processes involved, has been developed. This approach is often called *Physical Asset Management* (PAM), and it has shown important innovations and relevant changes in the maintenance management methods, especially in *asset intensive* companies such as those dealing with infrastructures and public utilities networks.

The main contributions of PAM regard a variety of issues such as:

- the organization, considering both PAM function, roles of personnel and cultural aspects;
- the PAM decision making framework and needed methodologies, such as those enabling Asset Life Cycle Management and Risk Asset Management;
- the Information System for supporting PAM;
- the asset performance measurement.

The next sub-sections focus on such issues, providing a short summary of the main items to be considered when defining what PAM is. Such items have been identified through a wide literature analysis, and have served as main background of what was developed in this thesis work. The objective of the thesis is thereafter presented.

Organization in PAM

Industrial organizations still live with the “mindset” of functional silos rather than adapting to a process orientation, hence the information and knowledge are fragmented between different functions and professions in the organization. Nonetheless, in asset intensive businesses, it is recommended to integrate the different functions so that the development, acquisition and operation of the assets are carried out effectively.

Integrating different functions and knowledge, the PAM function becomes often as a grey zone in the organization. But PAM without a defined position can't work efficiently and/or effectively. It is essential instead to define the role of Asset Management and the relations with other business functions, in order to avoid unproductive duplications and contrasts. In particular, the purpose of the PAM Function is to provide resources and expertise to support the acquisition, in-service support and disposal of the physical assets required by the organization. More precisely, the asset management function should provide inputs to asset planning, take a role in major acquisitions and developments, and provide the systems and facilities needed to support assets throughout their life-cycle.

For the wide range of responsibility and contributes, the PAM function needs to be in place along all the hierarchical levels of the organization: corporate, tactical and operational level. Often, the three levels of asset management are recognized by three different figures, responsible for different activities: the asset owner, the asset manager and the asset service provider. The asset owner is responsible for setting financial, technical, and risk criteria. The asset manager is responsible for translating these criteria into an asset plan. The asset service provider is responsible for executing the asset plans, and providing feedback on actual cost and performance. This structure allows each asset function to have a focus: owners on corporate strategy, managers on planning and budgeting, and service providers on operational excellence.

Asset owner, asset manager and service provider are only some of the roles belonging to the PAM group. In fact, this is a multidisciplinary group in which collaboration takes place amongst managers with suitable technical backgrounds and personnel in accounting and finance, legal, contracting, procurement and engineering roles.

Several personnel, with different backgrounds and organizational duties, can reach the goals of the organization only sharing a unique Asset Management Culture (being culture "*the set of shared attitudes, values, goals, and practices that characterizes an institution, organization, or group"*).

PAM decision making framework and methodologies

In literature there are different definitions of PAM. Asset management is defined by the PAS 55 as:*"systematic and coordinated activities through which an organization optimally and sustainably manages its asset systems, their associated performances, risks and*

*expenditures over their life cycles for the purpose of achieving its organizational strategic plan" w*here an organizational strategic plan is defined as: *"the overall long-term action plan for the organization that is derived from and embodies its vision, mission, value, business policies, objectives and the management of the risks"*.

From the definitions of PAS 55, the characteristics of PAM approach can be deduced and summarized in the following issues:

- holistic: it integrates management all of the aspects of the assets in contrast with specialized and compartmentalized approaches;
- systematic: it implies that PAM promotes consistent, repeatable and methodical actions, providing a clear support for decision making;
- systemic: it considers the assets as a system and tries to optimize the whole system, rather than optimizing individual asset in isolation;
- optimal: it tries to establish the optimal compromise between competing factors such as performance, cost and risk, associated with the assets over their life cycles;
- risk-based: the assessment of risks leads all the decisions;
- sustainable: PAM considers the potential adverse impact to the organization in the long term of short term decisions.

Therefore, PAM encompasses a broader and quite different set of activities from "maintenance". Maintenance is primarily concerned with keeping existing equipment in operating condition, while PAM is concerned with applying technical and financial judgment, and sound management practices, to–decide what assets need to meet the business aims, and then to acquiring and logistically sustaining the assets over their whole life, through to disposal.

In this new approach, the methodologies of life-cycle management and risk management become fundamentals.

Life cycle asset management gives a number of advantages such as enhance customer satisfaction, improve performance and control of product or service delivery, improve health, safety and environmental performance, optimize return on investment and/or

growth, enhance long-term planning confidence and performance sustainability, improve risk management and corporate governance.

The challenge in managing the entire asset life cycle effectively lies in the fact that costs are isolated and addressed in a fragmented way through the various stages. During the acquisition phase the emphasis is on implementing a technology within the boundaries of the approved budget and prescribed time frame, ensuring that the facility acquired conforms to the technical specifications. The primary drivers of the utilization phase are instead the associated costs of product distribution, spares and inventory, maintenance, training, etc..

According to life cycle asset management, life-cycle cost analysis considers costs from the acquisition to the disposal phase and can support management decisions in order to identify the option (new investment, repair,..) with the lowest life-cycle cost that allows to satisfy stakeholders' requirements.

Asset management does not regard only the minimization of costs but it is an integrated approach to balance costs, performance and risks during the asset life cycle.

There are different categories of risks to be considered when doing PAM: physical failure risks, operational risks, human factors, natural environmental events, factors outside the organization's control, supply risks, stakeholders risks. Indeed, the risk assessment is important in different areas of the organization and became fundamental in PAM Projects. The purpose of Risk Asset Management functions is to understand the cause, effect and the likelihood of adverse events which may occur while an asset is managed, and then to identify possible treatment of the risk, such as mitigation actions or contingency plans to reduce the impact of the adverse event.

PAM information system and performance measurement

Asset lifecycle management involves significant amount of acquisition, processing, and analysis of information that enable a variety of lifecycle aspects such as planning, design, maintenance, rehabilitation, and disposal/refurbishment or replacement of assets. Information Systems (IS) become then necessary in order to integrate the cross functional information.

The IS, in PAM context, has not only to provide support for decentralized control of maintenance tasks, but also to act as instrument for decision support, for example, in order to solve trade-offs between deferred maintenance and preventive maintenance, between short-term fixes and long-term solutions.

In terms of information flows, asset management represents a two-way process, where downstream information flows define strategies at each stage of asset lifecycle, and upstream information flows provide feedback on effectiveness of the implementation of these strategies. In order to know the efficiency and effectiveness of asset management, the assessment of asset performance has become an integral part of the business today. That measurement systems must reflect the context and the objectives of the organization. Lack of integration between various stakeholders and their changing requirements in strategic asset performance assessment is still a major issue for industries.

Objectives of the work

This Master of Science thesis work aimed at developing and testing a model for the maturity assessment of PAM practices. The inspiring idea was that the model should be developed in order to be adequate to be applied in different fields, in particular in the field of capital intensive manufacturing plants, services networks and infrastructures (water, energy, gas, railway infrastructure,...).

More deeply, the aims of this research were three:

- to study and understand the best practices emerged after PAM introduction;
- to define a maturity assessment methodology for companies who introduces PAM;
- to test the new methodology in real cases, in order to verify its capability to be applied in different fields.

Through literature review, PAM practices have been analyzed and classified in order to understand which are the key factors that companies need to take in considerations in managing their assets and how these elements influence business strategy and results. The previous section of this executive summary has already shown some insights on the outcomes of literature review.

Thereafter, from a methodological perspective, the work aimed at studying and enhancing the potentialities of pre-existent *maturity assessment* approaches. In other words, this thesis work wanted to pursue an integration to allow a further development and test of such pre-existent methodologies. The maturity assessment model, resulting from the integration, tries to combine their strengths so to finally define a flexible methodology which can be applied without sectorial bounders, both for the content assessed and for the terminology used.

Tests in real cases eventually aimed at verifying the capability of the model for maturity assessment to be applied in different fields. To this end, the main focus of interest for the test study were the followings:

- the ability of the model to discern the aspects that influence the maturity of the organization under assessment,
- the completeness of the model,
- the terms and contents used in the test, and their understanding from the target interviewee,
- the opportunities for further improvements of the methodology itself.

The methodology

A maturity model can be viewed as a set of structured levels that describe how well different processes of an organization are able to produce the required outcomes in a reliable and sustainable way.

This thesis work started from the comparison between two maturity models, both based on the Capability Maturity Model Integrated (CMMI) methodology. The former has been developed by a research group at Politecnico di Milano, Dept. of Management, Economics and Industrial Engineering; more precisely, the methodology is the result of the research activities carried out in the frame of *TeSeM* Politecnico di Milano. The latter has been developed by a research group at TU Delft, Faculty *Technology, Policy and Management* (TPM).

To better understand the Dutch approach, part of the work has been developed in the Netherlands, where many companies, especially in the infrastructure sector, have

successfully implemented PAM. In this respect, the research group of TUDelft represents a reference point in providing consulting services and support in understanding asset management principles.

The development reflects also other references from literature background in maturity assessment. In the remainder of this executive summary an insight is given on the TeSeM model and TUDelft model, as principal sources of inspiration.

TeSeM model

The purpose of TeSeM model is to analyze how maintenance practices are currently set up in an organization, especially focusing on how new practices were developed thanks to the advancement in the use of ICT tools/devices for diagnostics, prognostics and maintenance engineering. More deeply, this model aims at evaluating technological, organizational and management aspects in maintenance, defining three synthetic maturity scores summarizing company's behaviors. As a final outcome, the maintenance maturity is assessed both as a synthetic index, General Maturity Index (GMI), and as a set of component indexes accordingly with PAs (Process Areas) identified, Managerial (MMI), Organizational (OMI) and Technological (TMI).

Related questions were defined for each PA in a survey questionnaire. For every question, its related scores are defined according to the maturity scorecard, and thus interviewing the maintenance manager of a firm it is possible to calculate all the maturity indexes. The GMI is obtained multiplying the three indexes (GMI = MMI x OMI x TMI).

The TeSeM maturity assessment model – and its questionnaire – were developed based on a number of characteristics. First of all, it is *an "a priori" model*. This means that, for each answer in the questionnaire, it must be clear how to evaluate it in an unquestionable way, defining "a priori" a series of maturity levels. In this way, there will be no difference if maturity level is assigned by different interviewers/ evaluators. Second, thank to the use of closed-answer questions, it is adequate f*or a survey-like assessment* and the questionnaire is easier and quicker to fill in, and can be even used in phone interviews, or by less skilled people. Third, maturity levels are defined in order to understand which could be the possible further improvements to a maintenance system and this makes the model adapted *for a dynamic assessment*. Last, but not least, the model is designed f*or flexible adoption*, in order to be as much adaptable as possible at different needs and situations.

TUDelft model

The Infrastructure Maturity Model of TUDelft was developed under the request of Dutch Highway Transport Agency (RWS) in order to assess the maturity of the company and identify suggestions for improvement of PAM practices.

It is specifically designed on Asset Management maturity, so it pays more attention, as a default, on organizational and managerial aspects; moreover, the human factors are really linked to the strategy and the success of the company, and there are specific areas for the internal and external coordination. Precisely, the model investigates seven PAs that are: Information Management, Internal coordination, External Coordination, Market Approach, Risk Management, Process and Roles and Culture and Leadership.

The tool that supports the interviews and the assessment is not a survey-questionnaire but a *maturity matrix* in which the column are the PAs investigated and the rows the maturity levels. By using open questions the interviewers may have the opportunity to make more considerations about the maturity profile of the organizations, modifying the questions in relation to the answers given by respondents and clarifying possible doubts during the interview. In contrast, both data collection and analysis of the answers require more time and considerations, and it is linked to the experience of the interviewers. The analysis is particularly influenced by the knowledge of the sector and, hence, we cannot find the flexible propriety, strength of the TeSeM questionnaire.

The new model

The development of the model proposed in this thesis work has passed through the definition of a new maturity matrix, from which a new questionnaire has been derived as well.

The first step regarded the choice of how to develop the maturity matrix, indexes and process areas of each index. The three indexes used in the TeSeM model fit well with the analysis of a maintenance service but they omit important aspects that have to be considered in the extended field of PAM Assessment. On the contrary, the seven indexes identified in the TUDelft matrix are too linked to the field of application of the model: for example, the internal coordination – within this matrix – regards the divisional structure of the Road Authority and hence the need to structure a shared way to communicate between different departments.

Another consideration concerns the number of indexes, and their relationship with Process Areas (PAs) for which PAM practices are investigated. We selected the closed questions assessment, so for each PA we had to find a set of questions that can explain the maturity of that PA, in relation to different levels of PAM practices (basic, good, best … practices). Each PA was then associated to an index. This leaded to the need to solve a tradeoff between the depth of the analysis and the number of questions included in the questionnaire for maturity assessment. With a high number of maturity indexes, the assessment can cover more aspects/PAs of PAM, but we need to have a lot of questions: this might discourage the respondents. On the contrary, we had to find enough indexes through which we could do an exhaustive work of analysis through relevant PAs.

We identified then four important maturity indexes, used in order to calculate the maturity in different Process Areas. The indexes were also visualized in a maturity matrix (columns of the matrix).

- **Management Decisions**. It refers to the main decisions that the asset manager has to consider in managing the asset management of the firm, taking into account the asset life cycle management, risk management and maintenance management.
- **Information Management**. It refers to the aspects of information management related to ICT tools/systems, monitoring and prognostics methods, registration of data and performance management.
- **Organization and Culture**. Herein, we go in depth in the organizational issues. The asset management team, culture, communication and training are topics taken into account under this index.
- **External Coordination.** This index concerns the relationships with third parties such as stakeholders, regarding the ability to understand and follow their requirements, and contractors, regarding the shared information and plans.

Concerning the maturity levels, we decided to use the five levels defined along the continuum of the CMMI approach. The levels were associated to a correspondent maturity score.

- **Initial** (also chaotic, ad hoc, individual heroics): the starting point for use of a new or undocumented repeat process.

- **Managed** the process is at least documented sufficiently such that repeating the same steps may be attempted.
- **Defined**: the process is defined/confirmed as a standard business process, and decomposed to tactical and operational levels.
- **Quantitatively Managed**: the process is quantitatively managed in accordance with agreed – upon metrics.
- **Optimizing**: process management includes deliberate process optimization and improvement.

The resulting matrix – where the maturity indexes are the columns and the maturity levels are the rows – shows the progressive growth of maturity in the PAs: the correspondent textual description, characterizing each maturity level and index, synthesizes in fact the main practices achieved at that level. The following figure shows the matrix.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspects in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Fig.E.1 Maturity Matrix

Once designed the matrix, the questionnaire was derived.

Coherently with the prime purpose of the research - to develop a flexible model that can be applied both in the manufacturing and infrastructure sectors - we chose the closed questions methodology in which the evaluation of the answers has assigned a maturity score that is related to the definition given in the matrix and related maturity levels. This reflects also the a priori characteristic that allows (i) to force the respondent - the asset manager of the organization, or a close equivalent - to answer in a standard way (otherwise we might have different answers, possibly related to the sector of the company), (ii) to simplify the analysis of the answers in a general model and (iii) to enable cross comparison between the cases under analysis.

The tests in real cases

The test of the methodology (matrix and questionnaire) was carried out through an analysis of five case studies, three of which developed in Dutch companies, while the others in Italian ones.

The cases studies were developed with a dual purpose:

1. to assess the maturity of the interviewed companies in PAM practices;
2. to understand if the questionnaire – and consequently the model – analyzes the maturity in PAM practices in a complete and clear way (the respondents don't have doubt, the vocabulary used is appropriate, the results are consistent with their beliefs on the actual maturity of their organization, etc….), being applicable both in infrastructure and in manufacturing industry.

To test for the first time our questionnaire we asked one of the researcher, who developed the TUDelft matrix within the RWS context, to fill in it simulating to be the asset manager of RWS. This pre-test was developed in order to understand if the results of the new proposed model are coherent with the original TUDelft model.

The other cases regarded companies with different maturity. More deeply, a firm with a high maturity profile and one with a lower profile were chosen in the infrastructure sector (Dutch cases) , and two equivalent profiles were selected in the manufacturing field (Italian cases). This choice allowed to discern which are the aspects that influence the maturity, and to verify the existence of sectorial boundaries, in respect to the terms used and the content evaluated.

In developing the case studies, we asked to the respondents to fill in the questionnaire, underling doubts and cue of reflections. At the end, regarding the final/overall maturity of the company, we showed our matrix the respondents (except the lowest mature, since it was not considered ready for a self-assessment) and we asked them to indicate at which level they were, by their opinions.

Main results

The main outcomes of the research are:

- the maturity model itself that thanks to the use of standardized and well recognized terms, can be applied both in manufacturing plants and infrastructures;
- the “library” of PAM practices, now available in an unique source linked to maturity levels;
- the empirical evidence gained during the case studies.

In particular, the model assumes that PAM practices follow pre-defined roadmaps that pass through the implementation (the chaotic maturity level ML1), the partial management of the process (ML2), the standardization (ML3), the quantitatively management (ML4) and the optimization (ML5) phases. The pre-defined roadmaps emerges both from the descriptions in the maturity matrix and from the order of the answers in the questionnaire.

In fact, for each step of the roadmap, a set of PAM practices are defined. The respondent, reading the answers, can both make a self-assessment on his/her organization and envision what might be the possible developments to improve its PAM practices as if he had available a “library” of practices that guides the reflection.

Coherently with the aims of the tests, the results gained during the case studies refer to:

- the maturity assessment of PAM practices;
- the evaluation of the methodology.

Regarding the first aspect, the five following factors emerged as the key to discern the maturity levels in PAM practices:

1. completeness and effectiveness on management decisions of analysis (i.e. life cycle, risk, performance analysis);
2. information sharing (between different hierarchical levels and departments of the organization, but also with third parties);
3. integration of Information System (between different departments and with third parties);
4. sharing of a common culture (between different hierarchical levels of the organization);
5. “control of external factors” (stakeholders, service providers amongst the third parties).

In particular, the previous aspects increase passing from the lowest mature company to the highest one.

Lastly, the development of the case studies has not shown the existence of sectorial barriers in understanding of the specific terms of PAM, even in case of low maturity levels. For this reason we want to *encourage the research along the different sectors* that might extend the library of PAM practices and identify the boundary conditions that affect (positively or negatively) the implementation and the optimization of PAM practices.

Executive Summary

Che cosa è il Physical Asset Management?

Come conseguenza del sempre più aperto ambiente competitivo globale causato dalla pressione più elevata per ridurre i costi, aumentare i margini di profitto e, ultimo ma non meno importante, integrare i concetti di sviluppo sostenibile nella strategia di business, una visione della manutenzione diversa e più ampia, estesa a tutta il ciclo di vita degli asset e di tutti i processi coinvolti, è stato sviluppata. Questo approccio è spesso chiamato Physical Asset Management (PAM), e ha mostrato importanti novità e rilevanti cambiamenti nei metodi di gestione della manutenzione, soprattutto in aziende asset intensive, come quelle che si occupano di infrastrutture e di reti di public utilities.

I contributi principali di PAM riguardano una serie di questioni quali:

- l'organizzazione, considerando la funzione PAM, i ruoli del personale e gli aspetti culturali;
- il frame work di supporto al processo decisionale del PAM con specifiche metodologie, come ad esempio l'asset life cycle management e l'asset risk management;
- il sistema informativo per il supporto del PAM;
- la misurazione delle performance degli asset.

Le prossime sotto-sezioni si focalizzano su tali questioni, fornendo una breve sintesi delle principali voci da prendere in considerazione al momento di definire ciò che è PAM. Tali elementi sono stati identificati attraverso una vasta analisi della letteratura, e sono serviti da sfondo principale di quello che è stato sviluppato in questo lavoro di tesi. L'obiettivo della tesi è successivamente presentato.

Organizzazione in PAM

Le organizzazioni industriali vivono ancora con la "mentalità" dei silos funzionali, piuttosto che adattarsi ad un orientamento ai processi. L'informazione e la conoscenza sono quindi frammentate tra le diverse funzioni e professioni nell'organizzazione. Tuttavia, nelle imprese asset intensive, si consiglia di integrare le diverse funzioni in modo che l'acquisizione, lo sviluppo e la gestione degli asset siano svolte in modo efficace.

Integrando diverse funzioni e conoscenze, la funzione PAM diventa spesso come una zona grigia all'interno dell'organizzazione. Ma il PAM senza una posizione definita non può lavorare in modo efficiente e/o efficace. E 'essenziale, quindi definire il ruolo della funzione Asset Management e le relazioni con le altre funzioni aziendali, al fine di evitare duplicazioni improduttive e contrasti. In particolare, lo scopo della Funzione PAM è quello di fornire risorse e competenze per sostenere l'acquisizione, il supporto durante la fase di servizio e di smaltimento degli asset dell'organizzazione. Più precisamente, la funzione dell'asset management dovrà fornire input alla pianificazione, assumere un ruolo importante nella fase di acquisizione e sviluppo, e fornire i sistemi e le strutture necessarie per supportare le attività per tutto il ciclo di vita degli asset.

Per la vasta gamma di responsabilità e contribuiti, la funzione PAM ha bisogno di essere attiva, lungo tutti i livelli gerarchici dell'organizzazione: strategico, tattico e operativo. Spesso, i tre livelli di gestione degli asset sono riconosciuti da tre figure diverse, responsabili delle rispettive attività: il proprietario dell'asset (asset owner), l'asset manager e il fornitore di servizi dell'asset (asset service provider). L'asset owner è responsabile per la definizione dei criteri finanziari, tecnici, e di rischio. L'asset manager è responsabile della traduzione di questi criteri in un piano di attività. L'asset service provider è responsabile per l'esecuzione dei piani delle attività, e del monitoraggio dei costi e delle prestazioni effettive. Questa struttura permette ad ogni funzione di focalizzarsi su un aspetto preciso: l'asset owner sulla strategia aziendale, l'asset manager sulla pianificazione e il budgeting, e l'asset service provider sull'eccellenza operativa.

Asset owner, asset manager e asset service provider sono solo alcuni dei ruoli appartenenti al gruppo PAM. In realtà, questo è un gruppo multidisciplinare in cui collaborano manager con adeguato background tecnico e personale in ruoli contabile e finanziari, legali, contrattuali, appalti e ingegneria.

Diverse persone, con diversi sfondi e doveri organizzativi, possono raggiungere gli obiettivi dell'organizzazione solo condividendo un'unica Cultura di Asset Management (essendo la cultura "l'insieme di atteggiamenti, valori, obiettivi e pratiche che caratterizzano una istituzione, organizzazione o gruppo").

Frame work e metodologie decisionali del PAM

In letteratura esistono diverse definizioni di PAM. L'asset management è definito dalla PAS 55 come: *"L'insieme delle azioni e pratiche sistematiche e coordinate tramite le quali un'organizzazione gestisce in modo sostenibile e ottimizzato i suoi asset fisici, controllandone le performance, i fattori di rischio e i costi lungo l'intero ciclo di vita con l'obiettivo di raggiungere i propri obiettivi organizzativi e strategici*"

Dalle definizioni di PAS 55, le caratteristiche dell'approccio PAM possono essere dedotte e riassunte nei seguenti punti:

- globale: si integra la gestione di tutti gli aspetti degli asset in contrasto con approcci specialistici e compartimenti;
- sistematico: ciò implica che PAM promuove azioni coerenti, ripetibili e metodiche, fornendo un chiaro sostegno per il processo decisionale;
- sistemica: considera gli asset come un sistema e cerca di ottimizzare il sistema, piuttosto che ottimizzare le singole attività isolate;
- ottimale: si cerca di stabilire il compromesso ottimale tra fattori concorrenti quali le prestazioni, costi e rischi, associati agli asset lungo il loro ciclo di vita;
- in base al rischio: la valutazione dei rischi guida tutte le decisioni;
- sostenibile: il PAM considera il potenziale impatto negativo nel lungo termine delle decisioni a breve termine.

Pertanto, il PAM comprende una gamma più ampia e molto diversa di attività rispetto alla gestione della "manutenzione". La manutenzione è principalmente mantenere la macchina esistente in condizioni di funzionamento, mentre il PAM si occupa di applicare i principi tecnici e finanziari, e le pratiche di gestione, per decidere quali asset sono necessari per soddisfare gli obiettivi di business, e quindi di acquisire, e logisticamente sostenere gli asset lungo tutta la loro vita, fino allo smaltimento.

In questo nuovo approccio, le metodologie di gestione del ciclo di vita (asset life cycle management) e di gestione dei rischi diventano fondamentali.

L'asset life cycle management offre una serie di vantaggi, quali la soddisfazione dei clienti, il miglioramento delle prestazioni e il controllo della consegna del prodotto o dell'erogazione servizio, il miglioramento della salute, della sicurezza e delle prestazioni ambientali, l'ottimizzazione del rendimento degli investimenti e/o la crescita, l'aumento della fiducia nella pianificazione a lungo termine e delle prestazioni legate

alla sostenibilità, il miglioramento della gestione dei rischi e della corporate governance.

La sfida nella gestione dell'intero ciclo di vita degli asset si trova effettivamente nel fatto che i costi sono isolati e affrontati in modo frammentario attraverso le varie fasi. Durante la fase di acquisizione si pone l'accento sull'attuazione di una tecnologia entro i confini del bilancio approvato e del periodo di tempo prescritto, assicurando che l'impianto acquistato sia conforme alle specifiche tecniche. I driver principali della fase di utilizzo sono invece i costi connessi alla distribuzione dei prodotti, parti di ricambio e di inventario, manutenzione, addestramento, ecc.

Secondo il life cycle management, occorre considerare i costi globali dall'acquisizione alla fase di smaltimento, al fine di individuare l'opzione (nuovo investimento, riparazione, ..) con il più basso costo del ciclo di vita che consente di soddisfare le esigenze delle parti interessate.

L’asset management non riguarda solo la minimizzazione dei costi, ma si tratta di un approccio integrato per bilanciare i costi, le prestazioni e i rischi durante il ciclo di vita utile dell’asset.

Ci sono diverse categorie di rischi da considerare nell’approccio PAM: rischi di guasto fisico, rischi operativi, fattori umani, eventi ambientali naturali, fattori al di fuori del controllo dell'organizzazione, rischi di approvvigionamento, rischi per le parti interessate. Infatti, la valutazione del rischio è importante in diverse aree dell'organizzazione e diviene fondamentale nei progetti PAM. Lo scopo della funzione di Risk Asset Management è quello di capire la causa, l'effetto e la probabilità di eventi avversi che possono verificarsi durante la gestione di un asset, al fine di identificare possibili trattamenti del rischio, come ad esempio le azioni di mitigazione o piani di emergenza per ridurre l'impatto dell'evento avverso.

Sistema informativo e misurazione delle prestazioni nel PAM

L’Asset Life Cycle Management comporta una notevole quantità di acquisizione, elaborazione e analisi delle informazioni che consentono di gestire una varietà di aspetti del ciclo di vita tra i quali la pianificazione, la progettazione, la manutenzione, la riabilitazione e lo smaltimento/ristrutturazione o sostituzione degli asset. I Sistemi Informativi (IS) diventano quindi necessari, al fine di integrare le informazioni tra le diverse funzioni.

Il IS, nel contesto PAM, non ha solo il compito di fornire il supporto per il controllo decentralizzato delle attività di manutenzione, ma anche di agire come strumento di supporto alle decisioni, per esempio, al fine di risolvere i compromessi tra manutenzione differita e manutenzione preventiva, tra correzioni a breve termine e soluzioni a lungo termine.

In termini di flussi informativi, il PAM rappresenta un processo a due vie, in cui le sono presenti flussi di informazioni verso valle (da livello strategico e livello operativo dell'organizzazione) per definire le strategie in ogni fase del ciclo di vita e le risorse necessarie e flussi di informazioni verso monte (da livello operativo a livello strategico) che forniscono un feedback sull'efficacia dell'attuazione di queste strategie. Per conoscere l'efficienza e l'efficacia della gestione degli asset, la valutazione delle performance degli asset è diventata parte integrante del business di oggi. Questi sistemi di misurazione devono riflettere il contesto e gli obiettivi dell'organizzazione. La mancanza di integrazione tra vari soggetti e le loro esigenze mutevoli nella valutazione strategica delle performance degli asset è ancora un grosso problema per le aziende.

Obiettivi del lavoro

Il lavoro di tesi specialistica è finalizzato allo sviluppo e sperimentazione di un modello per la valutazione della maturità delle pratiche di PAM. L'idea ispiratrice voleva che il modello dovesse essere sviluppato per essere adatto ad applicazioni in diversi settori, in particolare nel settore degli impianti industriali ad alta intensità di capitali, reti di servizi e infrastrutture (acqua, energia, gas, ferroviaria, ...).

Più in profondità, gli obiettivi di questa ricerca sono stati tre:

- studiare e capire le migliori pratiche emerse dopo l'introduzione del PAM;
- definire una metodologia di valutazione di maturità per le aziende che introducono il PAM;
- testare la nuova metodologia in casi reali, per verificare la sua capacità di applicazione in diversi campi.

Attraverso la revisione della letteratura, le pratiche di PAM sono state analizzate e classificate in modo da capire quali sono i fattori chiave che le aziende hanno bisogno di prendere in considerazione nella gestione dei propri asset e come questi elementi influenzano la strategia di business e i risultati. La sezione precedente di questa sintesi ha già mostrato alcuni spunti sui risultati della revisione della letteratura.

Dal punto di vista metodologico, il lavoro è finalizzato allo studio e alla valorizzazione delle potenzialità dei approcci preesistenti di valutazione. In altre parole, questa tesi ha voluto perseguire un'integrazione per consentire un ulteriore sviluppo e test di tali metodologie preesistenti. Il modello di valutazione di maturità, risultante dall'integrazione, cerca di unire le forze in modo da definire finalmente una metodologia flessibile che possa essere applicata senza limiti settoriali, sia per il contenuto e che per la terminologia utilizzata.

I test in casi reali, infine, hanno voluto verificare la capacità, del modello di valutazione della maturità, di essere applicato in diversi campi. A tal fine, gli obiettivi principali di interesse per lo studio dei casi sono stati i seguenti:

- la capacità del modello di discernere gli aspetti che influenzano la maturità dell'organizzazione in esame,
- la completezza del modello,
- la loro comprensione dei termini e dei contenuti utilizzati nel test da parte dell'intervistato,
- le possibilità di ulteriori miglioramenti della stessa metodologia.

La metodologia

Un modello di maturità può essere visto come un insieme di livelli strutturati che descrivono il modo in cui i diversi processi di un'organizzazione sono in grado di produrre i risultati richiesti in modo affidabile e sostenibile.

Questo lavoro di tesi è iniziato dal confronto tra due modelli di maturità, entrambi basati sulla metodologia del Capability Maturity Model Integrated (CMMI). Il primo è stato sviluppato da un gruppo di ricerca presso il Politecnico di Milano, Dipartimento di Ingegneria Gestionale, più precisamente, la metodologia è il risultato delle attività di ricerca svolte nell'ambito dell'Osservatorio TeSeM del Politecnico di Milano. Il secondo è stato sviluppato da un gruppo di ricerca presso Delft University of Technology (TU Delft), Facoltà di Technology, Policy and Management (TPM).

Per capire meglio l'approccio olandese, una parte del lavoro è stato sviluppato nei Paesi Bassi, dove molte aziende, in particolare nel settore delle infrastrutture, hanno implementato con successo il PAM. A questo proposito, il gruppo di ricerca della TUDelft rappresenta un punto di riferimento nella fornitura di servizi di consulenza e supporto per la comprensione dei principi dell'asset management.

Lo sviluppo riflette anche altri riferimenti presenti nella letteratura della valutazione della maturità. Nella parte restante di questa sintesi è data una panoramica sul modello TeSeM e modello TUDelft, come principali fonti di ispirazione.

Modello TeSeM

Lo scopo del modello TeSeM è quello di analizzare come le pratiche di manutenzione sono attualmente impostate in una organizzazione, con particolare attenzione su come le nuove pratiche siano state sviluppate grazie al progresso nell'uso di strumenti ICT/ dispositivi per la diagnostica, prognostica e ingegneria di manutenzione. Più in profondità, questo modello si propone di valutare aspetti tecnologici, organizzativi e di gestione di manutenzione, attraverso la definizione di tre punteggi sintetici che riassumono i comportamenti aziendali. Come risultato finale, la maturità nella gestione della manutenzione è valutata sia con un indice sintetico, l'Indice di Maturità Generale (GMI), sia come combinazione di un insieme di indici, Indice di Maturità Manageriale (MMI), organizzativa (OMI) e Tecnologica (TMI) corrispondenti a PA (aree di processo) identificate.

Per ogni PA sono state formulate relative domande in un questionario di rilevazione. Per ogni domanda, sono definiti i punteggi secondo la score card di maturità e, quindi, intervistando il responsabile della manutenzione di una società, è possibile calcolare tutti gli indici di maturità. Il GMI si ottiene moltiplicando i tre indici (GMI = MMI x OMI x TMI).

Il modello di valutazione della maturità del TeSeM - e il suo questionario - sono stati sviluppati sulla base di una serie di caratteristiche. Prima di tutto, è un modello "a priori". Ciò significa che, per ogni risposta nel questionario, deve essere chiaro come valutare in modo indiscutibile, il livello di maturità. In questo modo, non ci sarà alcuna differenza se il livello di maturità è assegnato da diversi intervistatori/valutatori. In secondo luogo, grazie all'utilizzo di domande a risposta chiusa, è utilizzabile per un sondaggio/survey e il questionario è più facile e veloce da compilare, può essere anche utilizzato in interviste telefoniche, o con personale meno qualificato. In terzo luogo, i livelli di maturità sono definiti, al fine di capire quali potrebbero essere i possibili miglioramenti ulteriori in un sistema di manutenzione e questo rende il modello adatto per una valutazione dinamica. Ultimo, ma non meno importante, il modello è progettato per adozione flessibile, in modo da essere il più possibile adattabile alle diverse esigenze e situazioni.

Modello TUDelft

Il modello di maturità della TUDelft è stato sviluppato sotto richiesta dell'Autorità stradale Olandese (RWS), al fine di valutare la maturità della società e individuare proposte di miglioramento delle pratiche di PAM.

È progettato specificamente per le pratiche Asset Management, e quindi focalizza maggiormente la sua attenzione, come impostazione predefinita, sugli aspetti organizzativi e gestionali, e sui fattori umani per il loro legame alla strategia e al successo della società; inoltre, sono presenti aree specifiche per la coordinamento interno ed esterno. Precisamente, il modello indaga sette PAs che sono: gestione delle informazioni, coordinamento interno, coordinamento esterno, meccanismo di mercato, risk management, processi e ruoli e cultura e leadership.

Lo strumento che supporta le interviste e la valutazione non è un questionario per survey, ma una matrice di maturità in cui le colonne sono la PAs indagate e le righe i livelli di maturità. Utilizzando domande aperte gli intervistatori hanno l'opportunità di fare maggiori considerazioni sul profilo di maturità delle organizzazioni, modificando le domande in relazione alle risposte date dagli intervistati e chiarire eventuali dubbi durante l'intervista. Di contro, sia la raccolta dei dati che l'analisi delle risposte richiedono più tempo e considerazioni, legate all'esperienza degli intervistatori. L'analisi è particolarmente influenzata dalla conoscenza del settore e, pertanto, non si può trovare la flessibilità, forza del questionario TeSeM.

Il nuovo modello

Lo sviluppo del modello proposto in questa tesi è passato attraverso la definizione di una nuova matrice di maturità da cui è stato derivato un nuovo questionario.

Il primo passo consiste nella scelta di come sviluppare la matrice di maturità, quindi quali indici e aree di processo considerare per ciascun indice. I tre indici utilizzati nel modello TeSeM si adattano bene all'analisi dei servizi di manutenzione ma omettono aspetti importanti che devono essere considerati nella valutazione dell’esteso campo del PAM. Al contrario, i sette indici individuati nella matrice TUDelft sono troppo legati al campo di applicazione del modello: per esempio, il coordinamento interno - all'interno di questa matrice - riguarda la struttura divisionale dell'Autorità stradale e quindi la necessità di strutturare un modo condiviso la comunicazione tra i diversi reparti.

Un'altra considerazione riguarda il numero di indici, e il loro rapporto con le aree di processo (PA), per cui vengono indagate le pratiche PAM. Abbiamo scelto la valutazione a domande chiuse, quindi per ogni PA abbiamo dovuto formulare una serie di domande che possano spiegare la maturità della PA, in relazione ai diversi livelli di maturità delle pratiche PAM (di base, buone, pratiche migliori ...). Ciascuna PA è stata poi associata ad un indice. Questo ha portato alla necessità di risolvere un compromesso tra la profondità dell'analisi e il numero di domande inserite nel questionario per la valutazione maturità. Con un elevato numero di indici di maturità, la valutazione può coprire più aspetti/PAs del PAM, ma abbiamo bisogno di avere un numero considerevole di domande e questo potrebbe scoraggiare gli intervistati. Di contro, abbiamo dovuto trovare un numero sufficiente di indici attraverso i quali abbiamo potuto sviluppare un lavoro di analisi esaustivo attraverso le principali PAs.

Abbiamo quindi individuato quattro indici di maturità fondamentali, utilizzati per calcolare la maturità in diverse aree di processo. Gli indici sono stati anche visualizzati in una matrice di maturità (colonne della matrice).

- Gestione delle decisioni. Si riferisce alle principali decisioni che l'asset manager deve prendere in considerazione nella gestione degli asset della società, tenendo conto della gestione del ciclo di vita, gestione dei rischi e gestione della manutenzione.
- Gestione del flusso informativo. Si riferisce agli aspetti di gestione delle informazioni relative agli strumenti/sistemi ICT, metodi di monitoraggio e prognostici, registrazione dei dati e gestione delle prestazioni.
- Organizzazione e cultura. Qui, andiamo in profondità nelle questioni organizzative. La funzione e team del PAM, la cultura, la comunicazione e la formazione sono i temi presi in considerazione nell'ambito di questo indice.
- Coordinamento esterno. Questo indice riguarda i rapporti con i terzi, quali le parti interessate, per quanto riguarda la capacità di comprendere e seguire le loro esigenze, e fornitori, in merito alle informazioni condivise e ai piani.

Per quanto riguarda i livelli di maturità, abbiamo deciso di utilizzare i cinque livelli definiti lungo l'approccio continuo del CMMI. I livelli sono stati associati ad un corrispondente punteggio di maturità.

- Iniziale (anche caotico, ad hoc, eroismi individuali): il punto di partenza per l'utilizzo di un processo nuovo o non documentato.

- Gestito: il processo è almeno sufficientemente documentato, in modo tale che possa essere replicato ripetendo la stessa procedura.
- Definito: il processo è definito/confermato come un processo standard di business e decomposto a livello tattico e operativo.
- Quantitativamente gestito: il processo è quantitativamente gestito secondo metriche concordate.
- Ottimizzazione: la gestione del processo comprende l'ottimizzazione e il miglioramento del processo stesso.

La matrice risultante - in cui gli indici di maturità sono le colonne ed i livelli di maturità sono le righe - mostra la crescita progressiva della maturità nella PA: la descrizione corrispondente testuale, che caratterizza ogni livello di maturità e l'indice, sintetizza infatti le principali pratiche conseguite in quel livello. La figura seguente mostra la matrice.

	Gestione delle decisioni	Gestione del flusso informativo	Organizatione & Cultura	Coordinazione Esterna
5. Optimizzazione	Analisi life cycle cost e dei rischi sono sviluppate in modo completo e proattivo. La manutenzione è programmata seguendo i principi del miglioramento continuo.	L'informazione è parte centrale di un integrato processo decisionale, i dati/le informazioni sono facilmente disponibili. Le prestazioni dei processi sono monitorate al fine di supportare il processo decisionale.	AM è parte integrante della cultura dell'organizzazione. È presente un team AM multidisciplinare. I ruoli sono definiti in modo chiaro e la comunicazione è efficace. La formazione è vista come un fattore essenziale per il successo dell'organizzazione.	È presente un'attiva interazione con i legislatori; i principi dello sviluppo sostenibile guidano i piani strategici. I rischi e le prestazioni dei fornitori (di servizi e prodotti) sono continuamente monitorate.
4. Gestito Quantitativamente	L'importanza delle analisi LCC e dei rischi è riconosciuta ma le analisi non sono svolte in modo completo. L'organizzazione comprende l'importanza dei miglioramento continuo e sta cercando di standardizzare pratiche TPM e RCM.	CMMS/ERP/EAM sono strumenti usati per semplificare l'accesso ai dati/alle informazioni e per supportare le attività manageriali. L'analisi delle prestazioni ricopre differenti aspetti nell'organizzazione e influenza il processo decisionale ma non a tutti i livelli.	AM è riconosciuto come uno dei principi principali dell'organizzazione. L'importanza del training è compresa e comunicata.	Lo sviluppo sostenibile è uno dei principali obiettivi dell'organizzazione. I rischi e le prestazioni dei fornitori sono periodicamente monitorate con pratiche standard.
3. Definito	Analisi LCC e dei rischi sono sviluppate in modo strutturato ma si focalizzano solo sui principali aspetti della vita degli asset. Pratiche TPM e RCM sono occasionalmente svolte.	L'importanza di integrati e completi database è compresa ma è oneroso trovare dati/informazioni in essi. Pratiche standard per monitorare i principali KPI sono state sviluppate.	AM è uno dei principi dell'organizzazione. Il training è occasionale. L'organizzazione comprende l'importanza della comunicazione e cerca di incoraggiarla.	L'azienda cerca di considerare possibili future richieste/requisiti nei suoi piani strategici. I rischi e le prestazioni dei fornitori sono periodicamente monitorate senza pratiche standard.
2. Gestito	Alcune analisi LCC e dei rischi sono sviluppate ma sono ancora allo stadio iniziale. La manutenzione preventiva è pianificata in accordo all'esperienza degli operatori.	I dati/le informazioni non sono raccolte in database strutturati. I KPI sono monitorati senza pratiche standard.	L'organizzazione riconosce l'importanza dei principi dell'AM. Il training è solo nella fase di installazione dell'asset. C'è sfiducia nella comunicazione.	La sostenibilità è uno degli obiettivi minori. I rischi e le prestazioni dei fornitori sono occasionalmente monitorate.
1. Iniziale	Non c'è attenzione verso analisi LCC e dei rischi. Non esistono procedure standard per le attività di manutenzione .	I dati/le informazioni non sono integrati e le analisi dei dati e delle prestazioni sono povere o quasi inesistenti.	Non esiste una cultura dell'AM condivisa. I ruoli e le responsabilità sono ambigue. L'importanza del training è trascurata.	Non c'è nessuna interazione con i legislatori e con i fornitori. L'importanza della sostenibilità non è compresa.

Fig.E.2 Matrice di maturità

Una volta progettata la matrice, è stato derivato il questionario.

Coerentemente con l'obiettivo principale della ricerca - sviluppare un modello flessibile che possa essere applicato sia nel settore manifatturiero e che nelle infrastrutture - abbiamo scelto la metodologia a domande chiuse in cui alla valutazione delle risposte è assegnata un punteggio di maturità legato alle definizioni contenute nei livelli di maturità dei relativi matrici. Ciò riflette anche la caratteristica a priori che permette di (i) forzare l'intervistato – l'asset manager dell'organizzazione, o equivalente - a rispondere in modo standard (altrimenti potremmo avere risposte diverse, forse in relazione al settore del azienda), (ii) semplificare l'analisi delle risposte in un modello generale e (iii) consentire un confronto incrociato tra i casi analizzati.

Le prove in casi reali

Il test della metodologia (matrice e questionario) è stato effettuato attraverso l'analisi di cinque casi di studio, tre dei quali sviluppati in aziende olandesi, mentre i restanti in italiane.

I casi di studio sono stati sviluppati con un duplice scopo:

1. valutare la maturità delle imprese intervistate nelle pratiche PAM;
2. capire se il questionario - e di conseguenza il modello - analizza la maturità nelle pratiche PAM in modo completo e chiaro (gli intervistati non hanno dubbi, il vocabolario utilizzato è appropriato, i risultati sono coerenti con le loro convinzioni sulla maturità effettiva della loro organizzazione, ecc ....), e se è applicabile sia nelle infrastrutture che nel settore manifatturiero.

Per eseguire il test per la prima volta abbiamo chiesto a uno dei ricercatori, che ha sviluppato la matrice TUDelft nel contesto RWS, di compilare il nostro questionario simulando di essere l'asset manager di RWS. Questo pre-test è stato sviluppato per capire se i risultati del nuovo modello proposto siano coerenti con il modello TUDelft originale.

Gli altri casi considerano aziende con diversa maturità. Più in profondità, una società con un alto profilo di maturità e una con un profilo più basso sono state scelte nel settore delle infrastrutture (casi olandesi), e due profili equivalenti sono stati selezionati nel settore manifatturiero (casi italiani). Tale scelta ha consentito di discernere quali sono gli aspetti

che influenzano la maturità, e di verificare l'esistenza di confini settoriali, rispetto ai termini usati e il contenuto valutato.

Nello sviluppo dei casi di studio, abbiamo chiesto agli intervistati di compilare il questionario, sottolineando dubbi e spunti di riflessioni. Alla fine, per quanto riguarda la maturità finale/generale della società, abbiamo mostrato la nostra matrice agli intervistati (eccetto al rispondente della società meno matura, in quanto ritenuto non pronto per una auto-valutazione) e abbiamo chiesto loro di indicare a quale livello si attestassero, in base alle loro opinioni.

Principali risultati

I principali risultati della ricerca sono:

- Il modello di maturità stesso che grazie all'utilizzo di termini standardizzati e ben riconosciuti, può essere applicato in impianti di produzione e in infrastrutture;
- La "libreria" delle pratiche PAM, disponibili ora in un’unica fonte e legate al livello di maturità;
- L'evidenza empirica acquisita durante gli studi dei casi.

In particolare, il modello assume che le pratiche PAM seguono predefiniti roadmap che passano attraverso le fasi di attuazione (livello di maturità caotico ML1), gestione parziale del processo (ML2), standardizzazione (ML3), gestione quantitativa (ML4) e ottimizzazione (ML5). La roadmap predefinita emerge sia dalle descrizioni della matrice di maturità che dall'ordine delle risposte del questionario.

Infatti, per ogni passo del percorso di maturità, un insieme di pratiche PAM sono definite. L’intervistato, leggendo le risposte, può effettuare una auto-valutazione sulla sua organizzazione e immaginare quali potrebbero essere i possibili sviluppi per migliorare le pratiche PAM come se avesse a disposizione una "libreria" delle pratiche che guidi la riflessione.

Coerentemente con le finalità delle prove, i risultati ottenuti durante lo studio dei casi si riferiscono alla:

- valutazione delle pratiche di maturità PAM;

- valutazione della metodologia.

Per quanto riguarda il primo aspetto, i cinque seguenti fattori sono emersi come la chiave per discernere i livelli di maturità nelle pratiche di PAM:

1. completezza ed efficacia delle analisi nelle decisioni di gestione (ad esempio, analisi life cycle, del rischio e delle prestazioni);
2. scambio di informazioni (tra i diversi livelli gerarchici e dipartimenti dell'organizzazione, ma anche con soggetti terzi);
3. integrazione del sistema informativo (tra i vari dipartimenti e con soggetti terzi);
4. condivisione di una cultura comune (tra i diversi livelli gerarchici dell'organizzazione);
5. "Controllo dei fattori esterni" (stakeholders, fornitori di servizi tra i terzi).

In particolare, gli aspetti precedenti aumentano passando dall’azienda con più basso profilo di maturità a quello con più alto.

Infine, lo sviluppo di casi di studio non ha dimostrato l'esistenza di barriere settoriali nella comprensione dei termini specifici del PAM, anche in caso di bassi livelli di maturità. Per questo motivo vogliamo incoraggiare la ricerca lungo i diversi settori al fine di estendere la libreria di pratiche PAM e definire le condizioni al contorno che influenzano (positivamente o negativamente) l'attuazione e l'ottimizzazione delle pratiche PAM.

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Chapter.1 Research outline

This Chapter briefly introduces the research work, contextualizing it and highlighting its purposes.

Section **1** is dedicated to a description and a formalization of the objectives of this thesis; in Section **2**, the context of the present work is cleared out; finally, in Section **3**, an overview of the key steps of the research is provided.

1.1 Research objectives

This Master of Science thesis work aims at developing and testing a model for the maturity assessment of *Physical Asset Management* (PAM) practices, adequate to be applied in the field of capital intensive manufacturing plants, services networks and infrastructures (water, energy, gas, railway infrastructure,...).

More deeply, the aims of this research are:

- to study and understand the best practices emerged after PAM introduction;
- to define a maturity assessment methodology for companies who introduces PAM;
- to test the new methodology in real cases, in order to verify its capability to be applied in different fields.

From a methodological perspective, the work aims at studying and enhancing the potentialities of pre-existent *maturity assessment* approaches. The former has been developed by a research group at Politecnico di Milano, Dept. of Management, Economics and Industrial Engineering; more precisely, the methodology is the result of the research activities carried out in the frame of *TeSeM Observatory* (on Technologies and Services for Maintenance) of *School of Management* of Politecnico di Milano. The latter has been developed by a research group at Delft University of Technology (TUDelft), Faculty *Technology, Policy and Management* (TPM). This thesis work wants to pursue an integration to allow a further development and test of

the cited methodologies of *maturity assessment*. The development reflects also other references from literature background in maturity assessment.

1.2 Research context

Physical Asset Management (PAM) is spreading in a context in which many needs are issued.

- Society has become increasingly intolerant of industrial incidents, particularly in the areas of safety and environmental integrity: it is no longer considered acceptable to cause harm to either the environment or to people and the communities that they live in (Mather, 2003). In the last years this has been reflected in various changes in legislation and regulation in countries around the world and is leading companies to pay more attention to their impact on environment and society (Mather, 2003).
- Maintenance costs are often very high and they are following an increasing trend. One of the major factors behind this trend is that we are more dependent on machinery than in the past. Where previously people work, today machineries work. In fact, thanks to the development of automation and technology people are substituted by machineries in a lot of industrial sector (Dunn, 1987).
- Economic fluctuation and market uncertainty demand for higher profits and a better Return on Assets (ROA) and this can lead to very difficult and risky investment decisions. Characteristic for the capital-intensive industry is the need for large capital investments for both starting the business and running it, such as for machinery investments to increase capacity and the efficiency of production processes or to replace existing production equipment. In addition, resources are allocated to R&D to develop and produce new products and services (Räikkönen et al., 2010).

The next picture highlights main factors correspondingly involved in PAM.

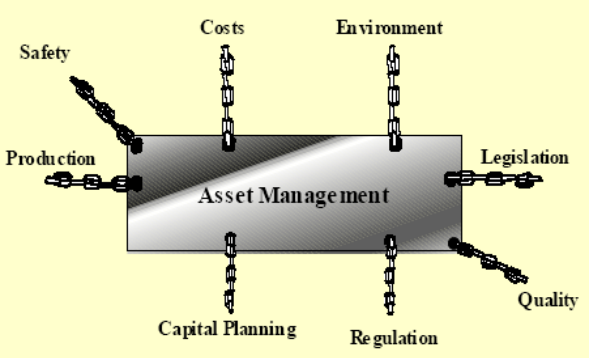

Fig.1. 1 Factors around PAM, from Mather, 2003

1.3 Research overview

The research follows four steps that are briefly described hereafter.

Step 1 – To review the state of the art of PAM

(see Chapter 2 for results)

Through a literature review we will try to understand what PAM means in different context and why companies are adopting this approach in managing their assets. In this review we will focus on the impact of PAM on the organization structure and on the main aspects of its business processes, such as life cycle cost management, risk management, information management and performance management.

Step 2 – To analyze the maturity models from literature

(see Chapter 3 for results)

At this step we go in depth on the study of pre-existent methodologies of maturity assessment. In particular, two models will be used as a guide for the development of the new one:

- TeSeM model
- TUDelft model

We analyze the strengths and the weaknesses of the two models trying to understand which are the methodological aspects that can be transferred to the new work.

A third model, developed by Port et al.(2010), has been selected from literature background, and it is used as an additional support.

Step 3 – To design a model for maturity assessment of PAM practices

(see Chapter 4 for results)

On the basis of CMMI (Capability Maturity Model Integrated) approach, the same of the models studied in the previous step, a new system for the assessment of PAM practices' maturity is designed. A questionnaire is also designed to this end, in order to make a characterization and a maturity assessment for a set of different case studies. The questionnaire is the "tool" for collecting data and information needed for maturity assessment.

Step 4 – To validate the model and analyze its use in different cases

(Chapter 5 and 6 for results)

A series of real cases are presented, in order to verify the capability of the new methodology to be applied in different fields.

Chapter 6 presents the concluding remarks of this work, both focusing on the outcome of the thesis as a whole, and fostering further research development for its improvement.

Chapter.2 Literature review on Physical Asset Management

This chapter offers a review of literature research about Physical Asset Management (PAM). After an introduction about the innovative aspects of PAM, such as the development of a new approach for maintenance and the interest in sustainability issues (Section **1**), the influences of PAM on organization is presented passing through the definition of PAM function, PAM group and PAM Culture (Section **2**). In Section **3** different visions and definitions of PAM that can be found in literature are discussed in order to explain what PAM means in this work. In the following sections we will go in depth in the main aspects of PAM, ranging from asset life cycle data management to information flows and asset knowledge (Section **4**) and we conclude with the theme of asset performance assessment (Section **5**).

2.1 An introduction of Physical Asset Management

This section of the thesis investigates which are the innovative aspects of PAM and why firms should need it.

2.1.1 What is a Physical Asset

The period of time that a physical asset may spend in each life-cycle stage is determined by its physical characteristics and by the nature of the business venture that the asset supports. Hence, managed assets with an approach based only on maintenance can't work efficiently and, on the basis of this general consideration, the Physical Asset Management (PAM) approach is developing and spreading (Amadi-Echendu, Managing Physical Assets is a Paradigm Shift from Maintenance 2004). This can be deduced from some part of literature, we want to go in depth in order to better understand, in real practice, what this does really mean.

First of all, we have to specify what the word *asset* means in this work because related to its meaning we can have different visions of PAM.

A general definition can be found in the Oxford Advanced Learner's Dictionary. Herein an asset is described as a "*valuable or useful quality, skill or person; or something of value that could be used or sold to pay debts*". This definition embraces different "things" and at the same time it considers the financial dimension as one important topic ("*to pay debts*").

We should make more explicit what such a "thing" is. Indeed, there are different types of assets. Some important categories that have to be managed are (PAS 55, 2008):

- physical assets,
- human assets,
- information assets,
- intangible assets
- financial assets.

Many aspects / properties, related to each asset, are linked and they may have a direct impact on the optimized management of each type of assets. We focus our work on physical assets.

Amadi – Echendu (2004) considers a physical asset as an *entity* that is capable of creating, sustaining or destroying value during each stage along its life-cycle (Amadi-Echendu, Managing Physical Assets is a Paradigm Shift from Maintenance 2004).

To clarify better the Amadi-Echendu's concept of *entity*, we consider that an asset is:

"plant, machinery, property, building vehicles and other items and related systems that have a distinct and quantifiable business function or service" (PAS 55, 2008)

2.1.2 The importance of Physical Asset Management

In accordance with the previous definition of physical asset, PAM can be considered a young science discipline, evolved from Maintenance Management (MM) to provide a holistic approach to managing the life of the physical asset (Katičić and Šušnjar, 2011). Indeed, according to the Amadi-Echendu's definition, referred in the previous sub-section, this corresponds to managing, at each stage along its life-cycle, the capability of the asset "*to create, sustain or destroy value*".

The major part of the life cycle costs is defined by the decisions taken in the early concept and design phase (Blanchard and Fabrycky, 1991). Furthermore, in capital-intensive industry, assets typically have long life cycles and major changes may occur

– during the progress of the life cycle – in all the exogenous or internal (endogenous) factors on which the investment calculations have been initially based.

Hence, the life cycle costs, the profits' objectives and cost structure have a significant influence on the asset strategy and strategic choices as well as its effective realization. Within the asset management framework, the challenge is on how to sustain or even improve the life cycle profits of the original investment during the operation and maintenance phase. Another essential question focuses on how to ensure high life cycle profits for Greenfield investments or major replacements with the design phase decisions.

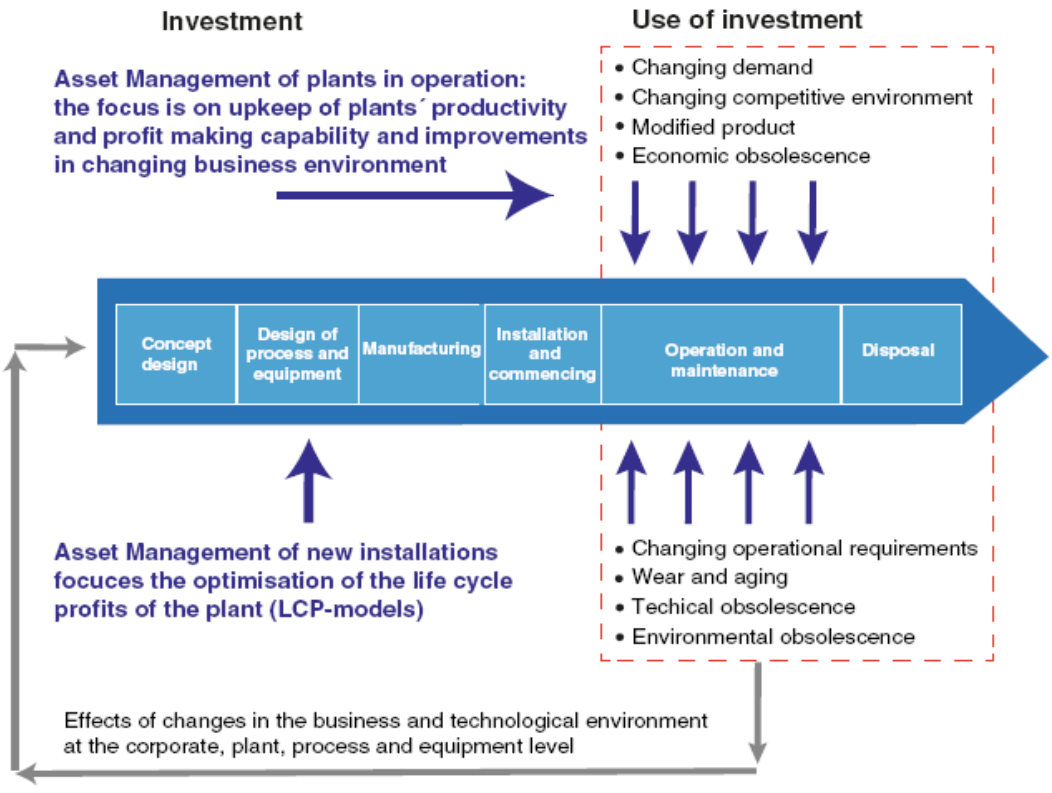

Fig.2.1 Investment life cycle and driving forces of asset management (from Komonen et al. 2012)

Very often, physical asset management has been considered as a wider view on maintenance management or as the bundle of the plant-level operations. But PAM is a huge field which includes (Komonen et al., 2012):

- creation, maintenance and improvement of the profit-making capability of production assets,
- maintenance and optimization of the net asset value of production assets, and
- improvement of sustainability and safety of asset solutions.

The first two themes are both related to the need to change the existing maintenance approach and to develop a modern one that considers assets during each phase of their life-cycle from concept/design to disposal. While the third theme is related to the spreading of the concept of sustainable development, that is "*meeting the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland, 1987)".

2.1.3 Changes in the maintenance approach

Most maintenance improvement initiatives today are functional in nature (Peterson, 2002). Firms that follow Functional Excellence Models believe that:

- operation owns production and maintenance owns equipment;
- maintenance excellence means efficient service to production;
- repair efficiency is the best measure of maintenance performance;
- production runs at any cost;
- goals are set by functional managers, resulting often in contradictory and self-defeating reward/recognition practices; further on, most measures are lagging indicators, demonstrating past results, while few leading indicators (or none) are considered to make a prospect on the future operation;
- purchasing excellence means having the lowest cost of items available;
- pressure is on individuals to do better; no gauges or tools of “better” exist.

So there is no attention to the system/to the whole organization and to match the goals of the other functions. Hence, we can assert these initiatives are somewhat limited in scope.

In an increasingly open global competitive environment caused by the higher pressure on costs, by the pressures to increase profit margins, or, in worse case scenarios, by the pressures to retain profit margins under lowering retail prices, a new mentality is being developed (Mather, 2003).

As a result, at a high level, we can state that a number of changes in the way of thinking can be found – when passing from maintenance management to physical asset management –. Herein, such relevant changes are briefly enlisted (Peterson, 2002):

1. The plant exists only for one reason — to produce as much product as possible, to specify and delivery schedules, at the lowest sustainable price
2. To improve will require fundamental changes in discipline and culture, beginning with the management team. Relationships and personal prejudices will be realigned
3. Everyone in the plant is on the same team and must work toward the same goals
    - shared vision of how the plant will work in the future
    - a multi-year plan for mastering new skills in asset management
    - a business case that continuously creates bottom-line value

As one of the largest elements of both operational and capital spending, physical asset management is often an obvious target for cost reductions. For example, the maintenance costs are often very high and they are following an increasing trend. One of the major factors behind this trend is that we are more dependent on machinery than past. Where previously people work, today machineries work. In fact, thanks to the development of automation and technology people are substituted by machineries in a lot of industrial sector (Dunn, 1987).

Due to the introduction of Reliability-Centred Maintenance (RCM), Total Productive Maintenance (TPM), Business-Centred Maintenance (BCM) and other methodologies and concepts, maintenance has already evolved a lot during the last decades (Waeyenbergha and Pintelon, 2006), to justify its own costs. However, a company in the process industry that solely applies these maintenance models cannot be really efficient as an estimated 65 percent of a company's life cycle cost (LCC) are set during the design phase (Barringer, 1997).

LCC considers the specification and design for reliability and maintainability of physical assets such as a plant, machinery, equipment, buildings and structures. The application of LCC also takes into account the processes of installation, commissioning, operation, maintenance, modification and replacement. Last but not

least, decisions are influenced by feedback of information on design, performance and cost, throughout the life cycle of a project (Waeyenbergha and Pintelon, 2006).

LCC helps then changing provincial perspectives for business issues, with emphasis on enhancing economic competitiveness by working for the lowest long term Cost of Ownership, which is not an easy answer to obtain. Let's consider, for example, these typical problems and conflicts observed in most companies (Barringer, 2003):

1. Project Engineering wants to minimize capital costs as the only criterion,
2. Maintenance Engineering wants to minimize repair hours as the only criterion,
3. Production wants to maximize uptime hours as the only criterion
4. Reliability Engineering wants to avoid failures as the only criterion,
5. Accounting wants to maximize project net present value as the only criterion, and
6. Shareholders want to increase stockholder wealth as the only criterion.

Management is responsible for harmonizing these potential conflicts and, according to the PAM concept, this may be done under the banner of operating for the lowest long term Cost of Ownership. LCC can then be used as a management decision tool for harmonizing the never ending conflicts by focusing on facts, money, and time.

LCC is only one of the instrument of the huge field of Life Cycle Management. In the Life Cycle Management approach emerges the awareness that maintenance activities have close relationships with activities in other phases of product life cycle, such as the design, production and end of life phase. These relations create the necessity for integration in terms of technologies as well as information throughout the product's life cycle so as to perform effective maintenance (Takata et al., 2004).

The effective maintenance, continue Takata et al.(2004), should involve the following activities:

1. improving design based on evaluating maintainability in the product development phase, and providing the design data for maintenance strategy planning and maintenance task control;
2. selecting a maintenance strategy appropriate to each part of the product;
3. planning and executing the maintenance tasks control based on the selected strategy;

4. evaluation of maintenance result to determine whether the maintenance strategy planning and maintenance task control are appropriate;
5. improvement of maintenance (task control and strategy planning) and products based on the evaluation of maintenance results;
6. dismantling planning and execution at the end of the product life cycle.

Summarizing, for PAM the life cycle perspective is key and its importance, as we will see better in next Chapter 3, is illustrated in numerous definitions of PAM. More than that, the maintenance approach may be related to such a life cycle perspective of the physical asset, as well as its life cycle costs. This helps motivating understanding of the new role of maintenance within PAM.

2.1.4 The sustainability issue

Sustainable performance today has become an economically sensitive issue that has an increasing potential to effectively and efficiently harness the emerging market demands for sustainable products and processes. It is a commercially important and a well thought business approach dedicated to long-term value with critical focus on stakeholders to better embrace opportunities, to reduce sustainability costs, and to manage hidden risks (DJSI, 2005) .

Society has become increasingly intolerant of industrial incidents, particularly in the areas of safety and environmental integrity (Mather, 2003). It is no longer considered acceptable to cause harm to either the environment or to people and the communities that they live in.

In the last years this has been reflected in various changes also in the legislation and regulation in many countries around the world and is leading companies to pay more attention to their impact on environment and society. Companies are becoming more aware of the need to perform their business in a sustainable manner.

Sustainable business activity in general implies:

"…adapting business strategies and activities that meets the needs of wider stakeholders of a commercial business (e.g. manufacturing, production, process) and also of the operator or the owner of the plant in question, through processes and products that has well-balanced and positive economical, social, and environmental implication." (Liyanage, Operations and maintenance performance in production and manufacturing assets: The sustainability perspective, 2007)

Businesses are then pressurized to incorporate economic, environmental and social performances in their policies, culture and decision-making processes.

These performance objectives manifest in three operational focal points that are fundamental to the manufacturing industry (Brenta and Visser, 2005):

- *Projects.* The concept of sustainable development must be integrated in the planning and management over the life cycle of projects, for example in terms of risk minimization.
- *Assets.* The life cycle of assets must be optimized in terms of sustainable development performance objectives of the manufacturing facility, for example in terms of maintenance cost minimization.
- *Products.* The influence of products on economies, environments and society as a whole must be considered, for example considering the concept of product stewardship.

PAM, with its holistic approach based on Life Cycle Management (and, subsequently, Life Cycle Costing), has become an useful instrument in order to assure that the operational processes are consistent, and that there is an effective sharing and coordination of resources, information and technologies during the whole life cycle of the assets, to adequately achieve the targets in sustainable performance.

2.2 Physical Asset Management in the organization

Historically, asset management has not been a well identified activity (Hastings, 2010) within the company's organization.

The industry organization still lives with the "mindset" of functional silos rather than adapting to a process orientation (Liyanage, 2012), so also the general pattern of educational and professional specializations results in a silo effect in the areas surrounding asset management.

Knowledge is then fragmented between different functions and professions in the organization. Engineers have skills in design, in technical development, and in the solution of technical problems, but this requires a focus which can create barriers which hide some aspects of business issues. Finance and accounting specialists are aware of fixed assets as a balance sheet entry whose technical depths are unknown.

Engineering and maintenance are often viewed as costs, to be minimized, and activities to be outsourced. Information technologists are skilled in establishing data management and communication systems, but the structure, content and use of the information lie elsewhere. Senior managers from political, legal, financial or marketing backgrounds often have priorities and short term imperatives which result in the lack of attention in the decision making for longer planning horizons (Hastings, 2010).

Nonetheless, in asset intensive businesses, it is essential to integrate the different functions so that the development, acquisition and operation of the assets are carried out effectively.

2.2.1 The "Grey zone"

Comprehensive and integrated PAM approaches require interdisciplinary know-how and competence (Komonen et al., 2012).

The wide field of competence of PAM results in the difficulty to represent it clearly in the business structure, like it happens with other business functions, such as Sales, Operations, Finance and Human Resource Management. So, PAM is often a "grey area", positioned between the business (senior) management and operational level (of maintenance) (Hastings, 2010).

Asset management without a defined position can't work efficiently / effectively in a company's organization. It is essential then to define the role of Asset Management and the relations with the other business functions, in order to avoid unproductive duplications and contrasts.

In particular, an asset management function is needed to provide asset knowledge and capacity for related management and decision support activities within the context of a business (Hastings, 2010). This particularly includes such issues as:

- asset (and associated capability) development planning and implementation,
- asset continuity planning and implementation,
- logistic support facilities development and management,
- applications in asset management and maintenance,
- shutdown / turnaround planning,
- collaborative operational risk management,
- development and management of maintenance outsourcing,
- information interfacing platform,

- awareness and management of regulatory compliance.

and many other activities (Liyanage, 2012; Hastings, 2010).

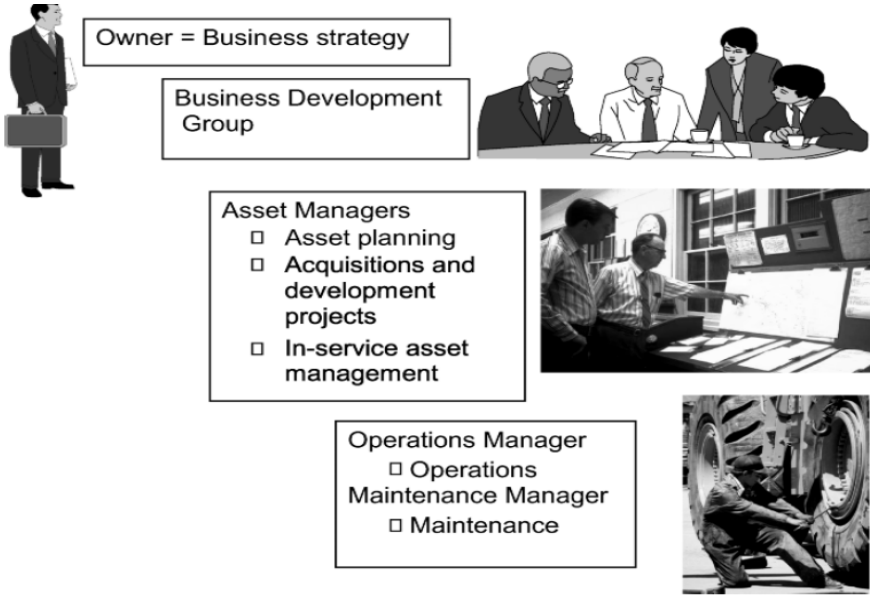

Fig.2.2 PAM as a "grey zone" between business development and operations management (sourced from Hastings, 2010)

2.2.2 How Physical Asset Management function should be

The purpose of the Physical Asset Management Function is to provide resources and expertise to support the acquisition, in-service support and disposal of the physical assets required by the organization. More precisely, the asset management function, when present at company level, should provide inputs to asset planning, take a role in major acquisitions and developments and provide the systems and facilities needed to support assets throughout their life (Hastings, 2010).

An essential step is to recognize PAM as an activity which requires representation at the Vice President or Chief Officer level. In fact, as all projects, it needs commitment at the high level of the organization to be effectively implemented (Hastings, 2010). This is illustrated in the Fig.2.3

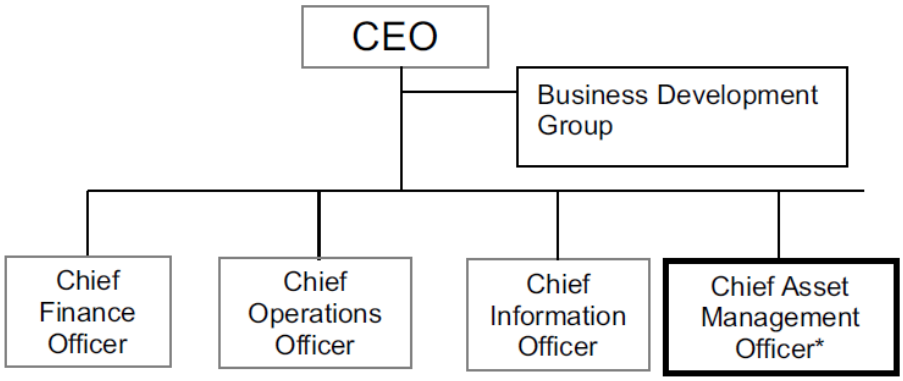

Fig.2.3 PAM in the organization – corporate level (sourced from Hastings, 2010)

Representation at the Chief level allows PAM to play its role in key asset related decisions and activities affecting the business.

At this level PAM is often called "Corporate asset management". Typical tasks at the corporate level include (Komonen, 2012):

- *portfolio management*, consisting of asset management activities that are executed to fulfill the requirements originating from the corporate strategy and objectives;
- *success factor management*, which aims at identifying factors and modes of operations creating the greatest competitive advantage;
- *capacity management*, incorporating the demand forecasts and competitive analyses for various products and production units;
- *life cycle management*, which at a corporate level calls for the executives to determine the expected economic lifetimes of various products and production units;
- *maintenance management*, which at a corporate level includes the definition of general policies for the maintenance function, such as outsourcing, building up of the ERP / information system support, defining the system of KPIs (key performance indicators), and taking care of the knowledge transfer between different plants.

All PAM activities do not concentrate only at the top / corporate level. Indeed, to carry out its function, Corporate asset management requires systematic decision making at

all organization levels. Hence, operating divisions, as they have own accounting staff, may also have asset managers looking after their own assets.

The Fig.2.4 illustrates how PAM at the divisional level can combine with asset management at the chief officer level.

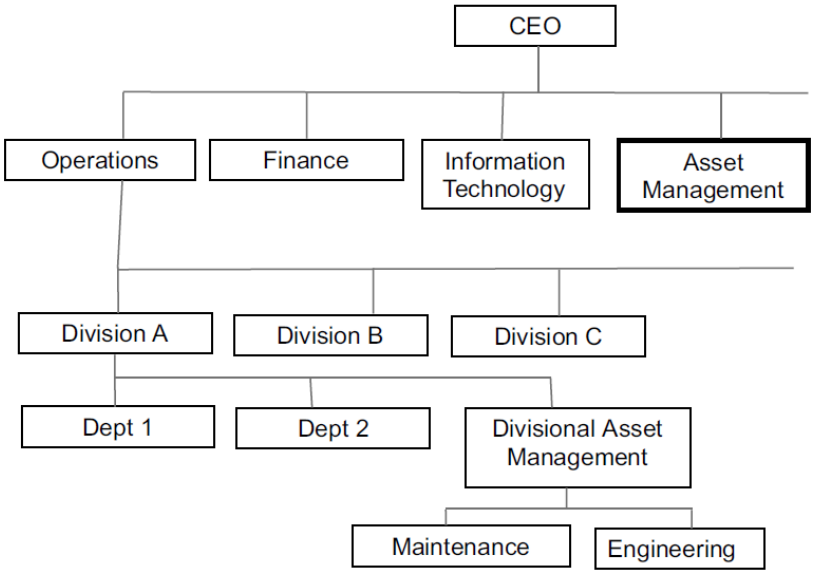

Fig.2.4 PAM in the organization – divisional level (sourced from Hastings, 2010)

Often in the organizations, the three levels (i.e. corporate, tactical and operational) of asset management are recognized by three different figures, responsible for different activities: the asset owner, the asset manager and the asset service provider (Brown and Humphrey, 2005).

The asset owner is responsible for setting financial, technical, and risk criteria. The asset manager is responsible for translating these criteria into an asset plan. The asset service provider is responsible for executing these decisions and providing feedback on actual cost and performance. This structure allows each asset function to have a focus: owners on corporate strategy, managers on planning and budgeting, and service providers on operational excellence (see Fig.2.5).

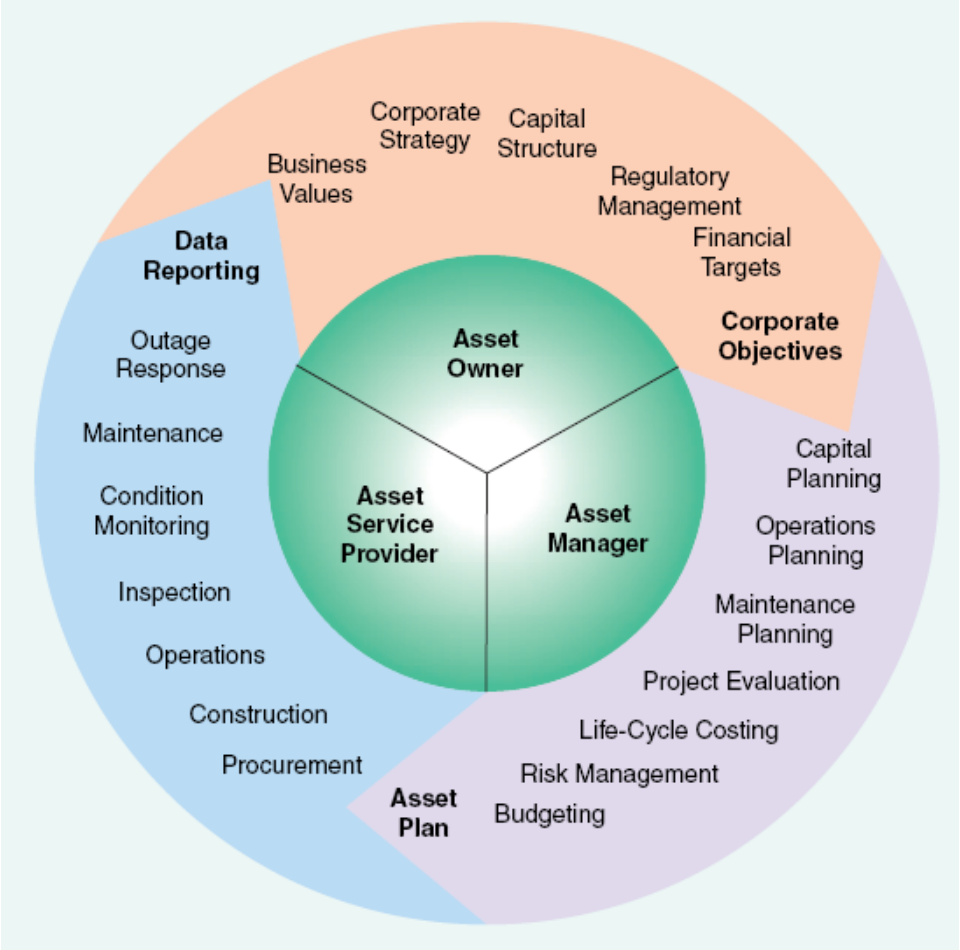

Fig.2.5 Asset management is based on three functions (asset owner, asset manager and asset service provider), a single process and many decisions (sourced from Brown and Humphrey, 2005)

2.2.3 Personnel roles in Physical Asset Management

Even if asset management activities and responsibilities impact on a wide range of roles within an organization and are not confined to a specific department, in a large organization, effective PAM will benefit from the existence of a recognized asset management personnel with expertise in specific areas. These may be formed into distinct groups, the title of which will depend on company's history and structure (Hastings, 2010). The asset management groups have key roles in acquisition and development decisions and projects, as well as in creating and managing organization-wide systems for equipment support for new and existing assets.

According to Hasting (2010), an asset management group normally consists of the following professionals: (i) asset managers with suitable technical backgrounds, and

(ii) personnel in accounting and finance, legal, contracting, procurement and engineering roles. The financial, legal and engineering staff should be co-located to asset management groups from their professional area. Moreover, for particular projects, teams will be formed with personnel numbers and skills dependent on the content and size of the project. The asset management groups form a basis from which these teams can be formed.

The asset management groups, just referred to, can involve hundreds of personnel in a large organization. In a smaller organization the same types of tasks are undertaken at a different scale, of course, but the same types of decisions are (or have to be) made. This means that the logic of the processes still carries through, even though the tasks may be handled by a works manager, a works engineer or a maintenance superintendent in among a range of other commitments (of course, with a diverse set of tools, capabilities and time to dedicate).

2.2.3.1 Examples of personnel roles

Hastings (2010) identifies the following personnel roles who take part of the asset management groups.

- ***Asset Manager***: An asset manager is involved not only with a single asset but with a particular range of them.

  Asset Managers require knowledge of relevant technologies and their operational context. They provide management and leadership for the group, and also provide input into business development in relation to their technical area. Asset managers usually come from engineering or logistic backgrounds, but they need to be familiar with the business in its broader context, and with general accounting and financial concepts.

  Asset managers have a key role to play in providing timely and sound input into business decisions above all for those based on estimates or forecasts made from the basis of combined technical and business knowledge.
- ***Project Manager:*** They have an important role in acquisition and developments project with their skill and experience.
- ***Finance, accounting and costing***: Personnel in these fields play an important role in assessing costs, assessing the financial viability of projects and in managing the finances of projects in progress.
- ***Lawyers***: Contracting and contract managers.

- ***Procurement managers and officers:*** They have the purpose of managing procurement and physical assets of the organization in line with the programmed strategy, work plan and financial plan.
- ***Engineers***: Engineers are required to provide technical knowledge essential to take decisions relating to the organization's physical assets. This includes technical knowledge of design and operation, and engineering and data analysis skills in reliability, maintenance, through life support and replacement decisions. Engineers may take "subject matter expert" roles which run across an organization.
- ***Logisticians***: They are required in order to apply such techniques as logistic support analysis and level of repair analysis. Other activities regard configuration management, cataloguing of spares, identification and coding of maintainable items of equipment, setting inventory control parameters and ensuring that the distribution system for assets, consumables and spare parts is appropriate to needs.
- ***General staff***: are also required covering human resource management and administrative functions.

2.2.4 Physical Asset Management Culture

In the previous section, we focused on the multidisciplinary aspects of the asset management group(s). But how professionals with different background, knowledge and goals can be working together? Organizations need a shared physical asset management culture to this end.

Culture is an ubiquitous term that many use, but rarely with consistency in meaning (Hofstede, 1984). Wikipedia defines it as "*the set of shared attitudes, values, goals, and practices that characterizes an institution, organization, or group*" (Culture, Wikipedia).

The Asset Management Council of Australia (AMC) defines Asset Management Culture as: *''the extent to which all levels of the organization have the knowledge, skills and commitment to achieve the documented asset management goals of the organization''*. The criteria used to evaluate this component are listed below:

- How are Asset Management goals deployed at all levels?
- Are these evident to all people involved?

- Are the knowledge and skills necessary for achieving Asset Management performance goals known by the enterprise?
- Is there a plan for the provision of Asset Management knowledge and skills?
- Are the roles and responsibilities for those involved in Asset Management clearly defined?
- How is the performance of individuals and groups recognized and supported?

It can be seen that the AMC's definition and criteria fail to evaluate the desired shared values, behavioral norms and beliefs present within the today's organization, so it does little to identify attributes that may drive excellence in engineering practices (Murphy, 2010). Henceforth, it is important to develop a shared organizational culture, because the success of an enterprise depends also upon people who work in there, thanks to their knowledge and skills, and the human capital.

There is a lack of research examining the impact of human capital on physical asset management; this is especially important today, considering that (Woodhouse, 2001) suggests that this is the weakest link in asset management.

Intellectual capital is an important concept which includes: human capital, structural capital and relationship capital. Furthermore, structural capital involves the organizational infrastructure which in this case supports the process of managing assets (this includes technology such as databases and management systems, used for asset information management) (Dawson, 2000). Therefore, if human capital is important to physical asset management, according to the literature and theory about intellectual capital it may also be important to increase other issues, such as the relationship capital between the employees, in order to improve infrastructure and engineering asset management performance, and increase overall human capital within the organization (Subramaniam and Youndt, 2005).

Even if the importance of the culture in the physical asset oriented enterprises was recognized from many authors, the research on this field has been only recently developed.

Murphy (2008) and Jung et al. (2009) propose that organizational culture may be critical for effective engineering asset management. Specifically, Murphy (2008) suggests that EAM (Engineering Asset Management) researchers need to identify ideal organizational cultures for supporting and developing effective asset management processes. He suggests few organizations are pursuing 'best practice'

engineering culture. As a follow up of this statement, he adopted qualitative research methods to identify factors facilitating an effective EAM culture. The factors so highlighted can be categorized into individual, group and organizational factors. The individual factors include: openness to change and flexibility, contentiousness, technical and engineering skills. On the other hand, the group factors are: communication, co-operation and collaboration. Last but not least, the organizational factors are: quality and continuous improvement, safety and environmental focus, and business and commercial focus. Jung et al., (2009) extended the argument by suggesting a process for managing organizational culture and organizational culture change, because typical EAM cultures must change if they are going to meet best practice standards and to maximize asset management performance.

There are numerous studies that suggest organizational culture impacts on the overall effectiveness of the organization. For example, it has been suggested that organizational culture may impact on organizational factors such as: morale, job satisfaction and organizational commitment (Armenakis and Stanley, 2002).

Therefore, it is very important to understand how organizational culture is seen by the employee. But, if it is difficult to define organizational culture, it is even more difficult to examine it, due to the lack of instrument, or test it. This difficulty for defining and testing the organizational culture could be clearly attributed to its social nature and complexities; for example, the unspoken rules about acceptable attire, how to speak and act in certain situations, and how to react during particular social exchanges (Brunetto and Xarri, 2012).

Different authors agree with the need to use an approach based on mixed methods, both qualitative and quantitative. In particular, “leadership, communication, teamwork, commitment to innovation, and attitudes to change” can be measured using a quantitative approach, while values and assumptions can be examined using interviews or focus groups (Scott et al., 2003). To provide further information, Schein (1990) suggested that quantitative measures of organizational culture are not suitable for measuring underlying beliefs and assumptions.

In addition, Hofstede (1998) suggests that values and attitudes, which he refers to as constructs, are not directly observable and should be measured by attaining value statements or by examining workplace behavior.
Also Brunetto and Xerri (2012), although they develop their work considering only quantitative indicators, recognize that overall an approach based on mixed methods

to measuring organizational culture may provide more holistic results. In their study, that aims to validate a measure to examine the organizational culture of infrastructure and engineering asset management organizations, they use an organizational culture survey developed by Glaser et al. (1987) to examine teamwork and morale and they examine it in addition to leadership, communication, commitment to innovation and attitudes toward organizational change, combining with the prescriptions of Scott et al. (2003).

Concluding, culture is a relevant issue in Physical Asset Management, and it is then important to understand how much it is developed in an organization, and if there is need to further improve it. This is not an easy task, because many factors have to be considered (according either to the general theory of intellectual capital or to the specific studies on culture in Physical Asset Management) and, further on, not all of these factors can be measured quantitatively.

2.3 What is Physical Asset Management

It is now worth deepening the comprehension of PAM in respect to what it does within an organization.

PAM is a young science discipline evolved from Maintenance Management to provide a holistic approach to managing the life of a physical asset (Katičić, 2011). Holistic approach means that it integrates the management of all the aspects of the assets in contrast with specialized and compartmentalized approaches (which is what happens with the traditional approach to maintenance management, see what said in paragraph 2.1.3). Only considering this characteristic of PAM may however lead to a reductive definition of it. We have then to consider others aspects of PAM approach, such as the following features:

- systematic: it implies that PAM promotes consistent, repeatable and methodical actions, providing a clear support for decision making;
- systemic: it considers the assets as a system and tries to optimized the whole system rather than optimizing individual asset in isolation;
- optimal: it tries to establish the optimal compromise between competing factors such as performance, cost and risk, associated with the assets over their life cycles;
- risk-based: the assessment of risks leads all the decisions;

- sustainable: PAM considers the potential adverse impact to the organization in the long term of short term decisions.

Different definitions of PAM can be found in literature, focusing on different aspects out of those now discussed.

2.3.1 Definitions of Physical Asset Management

Asset management is defined by the PAS 55 as:

"systematic and coordinated activities through which an organization optimally and sustainably manages its asset systems, their associated performances, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan".

Where an organizational strategic plan is defined as:

"the overall long-term action plan for the organization that is derived from and embodies its vision, mission, value, business policies, objectives and the management of the risks"

The definition shows that asset management is seen as the whole of activities that the organization undertakes to achieve its organizational strategic plan. From this viewpoint, assets are a central part for the operational success of the organization. In general, one can say that PAM activities aim to get the most value out of the physical assets in an asset intensive organization - where value is related to the organizational goals of a company (PAS 55, 2008) .

Other authors say that asset management is an integrated approach to balance costs, performance and risks during all asset life cycle (Wijnia, 2009) and it is often one of the last options to maximize cost savings in a competitive global economy due to its intrinsic complexity, especially in many developing countries (Brent et al., 2005).

A reason for the existence of different asset management concepts might therefore be driven by the nature of the different assets. The definitions are related to the context in which assets are and show a common general meaning so we can say that asset management is a single approach that is implemented differently in different industries. The way through which it is developed depends on the characteristics of the assets and the environment of the assets, in relation to the most relevant lifecycle phases and management of the organizations (Van der Lei et al., 2010).

Other interpretations of PAM are related on the type of approach. Professionals in Operations and Maintenance have a bottom up approach and see asset management as a way to professionalize their work. Conversely, the corresponding top down view sees asset management as a performance strategy. This strategic asset management view is held by management professionals. Finally, asset management can be seen as way to add value to delivered (public) services. This view belongs predominantly to service providers in networked infrastructures (e.g. energy network).

All the previous definitions show clearly that asset management encompasses a broader and quite different set of activities from “maintenance”. Maintenance is primarily concerned with keeping existing equipment in operating condition, while physical asset management is concerned with applying technical and financial judgment, and sound management practices, to deciding what assets need to meet the business aims, and then to acquiring and logistically sustaining the assets over their whole life, through to disposal (Hastings, 2010).

In this work PAM is defined as:

“the set of activities that an organization undertakes to manage asset during the whole life-cycle, from the design/acquisition phase to the disposal, in order to maximize performances and minimize risks and expenditure”.

In other words, PAM is a systematic and integrated approach through which physical assets are managed in a sustainable way during the whole life-cycle. In the following sections we will study in depth three important aspects of PAM which can be deducted from the previous definitions: the Asset Management System, the Asset Life Cycle Management and the Risk Asset Management.

2.3.2 Asset Management System

Delivering the best value for money in the management of a physical asset is complex and involves careful consideration of the trade-offs between performance, cost and risk over all stages of the asset’s life cycles, such as short-term versus long-term benefits, expenditures versus performance levels, planned versus unplanned availability, or capital costs versus operating expenditures (PAS 55, 2008).

The first step to do when managing an asset is to understand at which level it is identified and analyzed. In fact, it could be seen as discrete equipment items or as a

component of complex functional systems, network, sites or diverse portfolio (Fig.2.6).

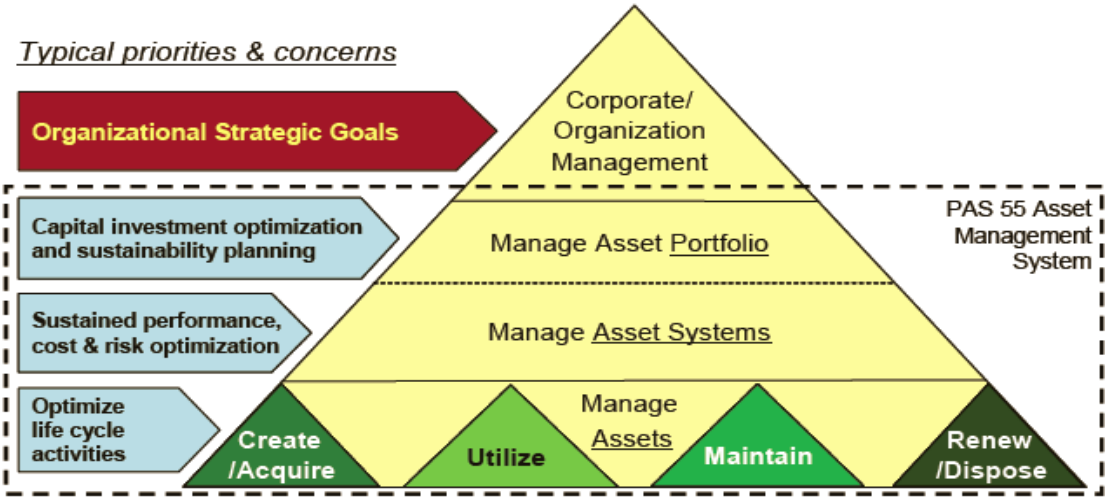

Fig.2.6 Asset Management System from PAS 55, 2008

Each different level has its own challenges and opportunities. For example, discrete equipment items may have identifiable individual life cycles that can be optimized, whereas asset systems may have an indefinite horizon of required usage. A larger organization may also have a diverse portfolio of asset systems, each contributing to the overall goals of the organization, while presenting widely different investment opportunities, performance challenges and risks.

Managing investment portfolios is especially important for companies in capital-intensive industry. During times of economic fluctuation and market uncertainty, the demand for higher profits and a better return on assets (ROA) can lead to very difficult and risky investment decisions. Characteristic for the capital-intensive industry is the need for large capital investments for both starting the business and running it, such as machinery investments either to increase the capacity and the efficiency of production processes or to replace existing production equipment. In addition, resources are allocated to R&D in order to develop and produce new products and services (Räikkönen et al., 2010). All these high expenditures in uncertain context motivate the challenges encountered in managing investment portfolios in such a type of companies.

Komonen et al. (2006) developed a framework based on the business objectives of the firm and on analyzing and modeling various businesses and business environments from the standpoint of the physical assets taking into account the technological characteristics, economic structure and uncertainty in the industrial sector in question.

According to such a framework, management decisions are expected to be aligned at different levels.

- The corporate strategic decisions reflect corporate visions, values and business objectives and incorporate the information from strategic analyses and scenarios.
- If the firm has several production facilities or plants, the local asset-related decisions need to be in line with the corporate asset strategy and take into account the plant-level objectives and constraints. At this stage, the technical and economic analysis and risk analysis create important inputs for the decision-making.
- The plant or production asset strategy is allocated to the production systems and equipment and forms a basis for decision-making at the shop floor level.

The Asset management decision making framework proposed by Komonen et al. is synthesized in fig. 2.7.

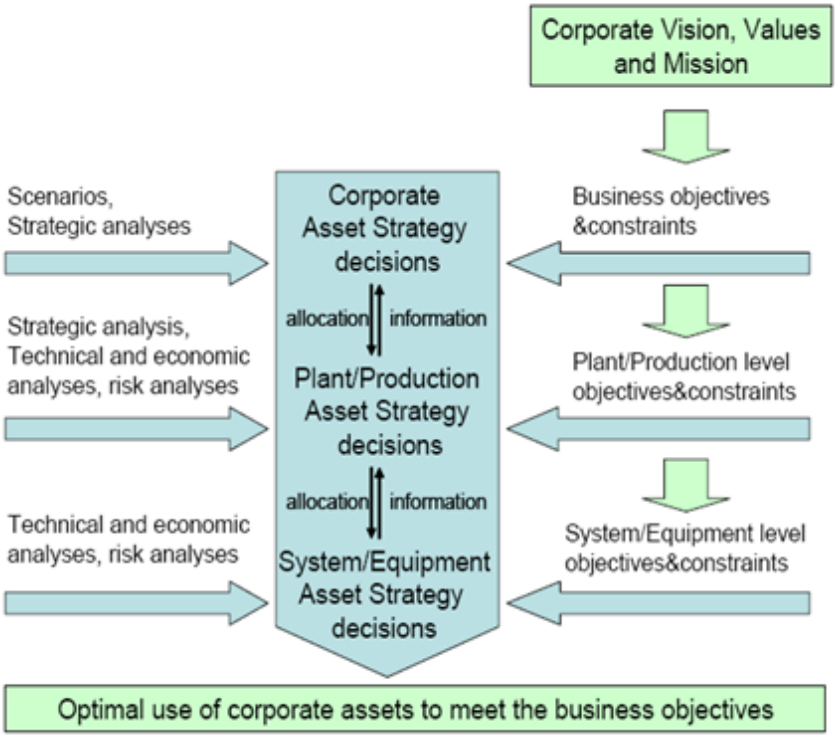

Fig.2. 7 Schematic presentation of the Asset Management decision making framework from Komonen et al., 2006

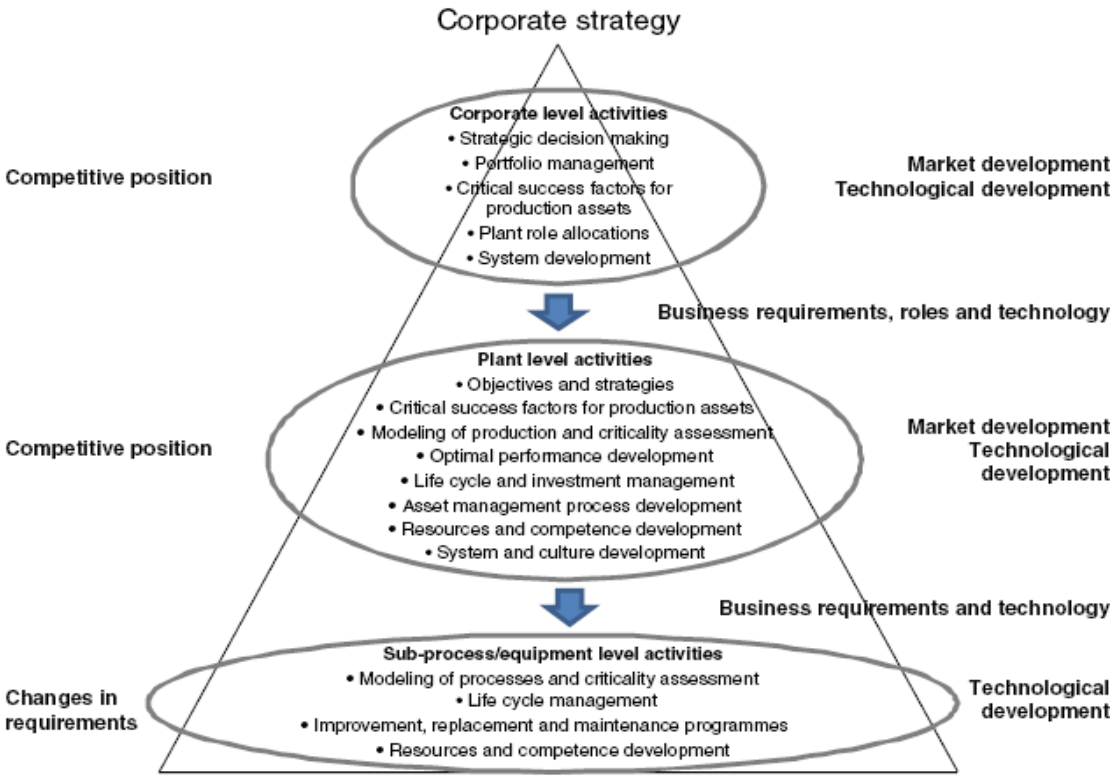

Fig.2.8 Asset Management levels: framework and holistic management of production assets from Komonen et al., 2012

The asset management tasks and activities and responsibilities at each level are summarized in Fig.2.8, which also illustrates the preconditions, supporting systems and tools needed in order to implement effective asset management at each level. For example, the corporate executives should determine the role of each production unit. The plant-level management should model the production system, carry out criticality assessment, determine optimal performance and plan the road map for the future development. At the production line, sub-process or equipment level, the important management processes would be, e.g., modeling of processes or technical functioning of equipment and taking care of criticality assessment (Komonen et al., 2012).

The proposal from Komonen et al. can be considered one of the most recently produced in the scientific literature. It can be thought as an asset management system particularly aimed at integrating the different levels of decision making in an industry organization. This proposal shares a similar view of PAS 55 on the need to integrate decisions at different levels.

In particular, according to PAS 55, an integrated asset management system is essential to coordinate and optimize the diversity and complexity of assets in line with the organization's objectives and priorities. An asset management system is primarily designed to support the delivery of an organizational strategic plan in order to meet the expectations of the variety of stakeholders, such as customers, society, shareholders, suppliers and employees. The asset management policy, strategy, objectives and plans are then established in accordance with the organizational strategic plan. These, in turn, direct the optimal combination of life cycles activities to be applied across the diverse portfolio of assets systems (in accordance with their criticalities, condition and performance) (PAS 55, 2008).

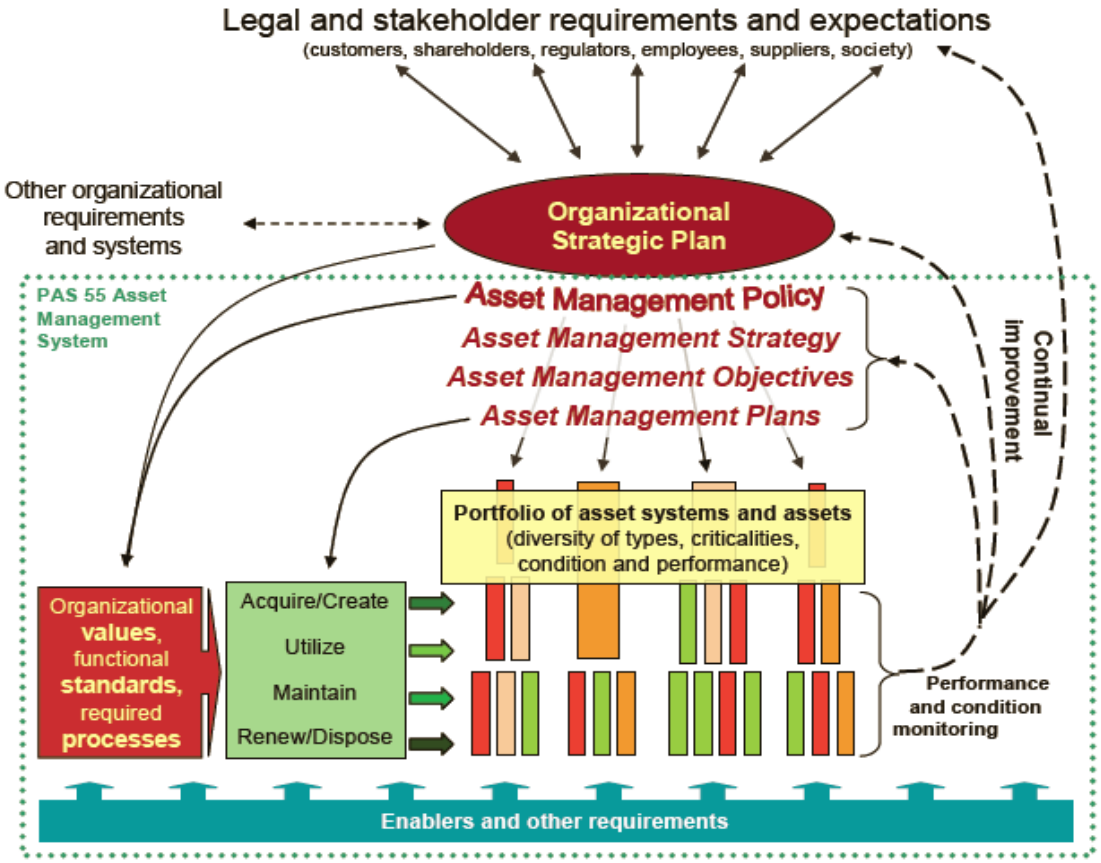

Fig.2.9 PAM: how to reach the strategic plan, source IAM, 2010

Fig.2.9 highlights that the relationships between these factors are not fixed. Through the monitoring and continual improvement, not only the internal aspects of organization (policy, strategy, objective, plans) are continually reviewed, it is also demonstrated the importance of continual improvement externally through direct influence upon the organizational strategic plan and stakeholder expectations. The transparent linkage between organizational strategic direction and the day-to-day activities of managing assets is a vital component of asset management system. This linkage aligns the "top down" aspirations of the organization with the "bottom up" realities and opportunity of assets (PAS 55, 2008).

Also in PAS 55, we can find the following useful definitions, which is worth to mention for achieving a full identification of principal components of an asset management system.

- **Asset Management Policy:***"principles and mandated requirements derived from, and consistent with, the organizational strategic plan, providing a*

framework for the development and implementation of the asset management strategy and the setting of the asset management objectives". Other aspects of policy may cover the assignment of authority and responsibility for specific areas of asset management to various office holders. The asset management policy is a means of top management to communicate to its managers, employees and stakeholders the organization's position and intention with regard to asset management. It provides a high level statement of the organization's principles, approach and expectations relating to asset management and identifies all legal, regulatory and statutory and other asset management requirements, including the requirements of the organizational strategic plan.

- **Asset Management Strategy:** "*is a broad level plan set by senior management as a guide to how an organization intends to achieve its aims*". The asset strategy also specifies authorities and responsibilities for action in relation to asset management activities. These may be incorporated in more generally based documents such as organization charts and job descriptions, but it is important that the asset management aspects are covered.
- **Asset Management Objectives** "*Specific outcome or achievement required of assets, asset type and/or asset systems in order to achieve the asset management strategy".* The asset management objectives must be continually reviewed, so that they are not in contrast with legal, regulatory statutory and other asset management requirements, with financial, operational and business requirements, and they have to consider asset-related risks and the expectations of stakeholders.
- **Asset Management Plan**: as said before, it is defined as "*the overall long-term action plan for the organization that is derived from and embodies its vision, mission, value, business policies, objectives and the management of the risks*". It has to be optimized in a continuous process and it also provides the allocation of suitable resources (financial, human, equipment, logistics). Asset management plans can be for individual assets, asset type and/or asset system. However, it is essential that the plans are linked to the asset management policy, strategy, objectives and targets that they are intended to achieve. The asset management plan shall include documentation of the designated responsibility and authority and the means and the time-scale by which asset management, objectives and targets are to be achieved.

2.3.2.1 Strategic Asset Management

It is now worth providing a short, further in-depth on the relationship existent between organizational strategic plans and the asset management strategy.

Referring again to PAS 55, asset management is defined as the whole of activities that the organization undertakes to achieve its organizational strategic plans. This is in contrast to the traditional idea that assets are only maintained to keep its value and capability. Instead, all the operations and maintenance activities are now managed to reach the vision of the company. As a result, a company can achieve business success through PAM (Zhuang, 2011).

The asset management strategy is then closely linked to the business strategy. Some issues deriving from the business situation which impact on asset management strategy include the followings (Hastings, 2010):

- changes in demand for product or service;
- changes in revenue and costs;
- technological developments;
- new business developments;
- acquisitions;
- divestment, sale or phasing out;
- redeployment;
- changed operating practices;
- equipment replacement/Leasing;
- outsourcing or In-sourcing of services.

Other factors are related to how the organization wants to resolve the trade-offs in decision making, such as for example:

- planning for a long term growth versus just doing enough to meet short term requirements;
- having a degree of commitment to in-house repair and logistic support versus outsourced support facilities;
- using the redundancy to achieve system reliability rather than seeking high reliability of individual items;
- keeping a defined maintenance and replacement strategy in regard to run-to-failure, age-based, condition-based, spend-limit based replacement decisions.

2.3.3 Asset Life Cycle Management

The life of an asset is determined both by the correct use and maintenance and by its physical characteristics which are fixed in the design phase. For this reason an approach based only on maintenance can't work efficiently. Physical asset management trays to overcome the limits through an approach which have an impact over the whole life of the asset (Hastings, 2010).

The principal benefits of optimized life cycle asset management, identified by PAS 55, are the followings:

- enhanced customer satisfaction from improved performance and control of product or service delivery to the required standards;
- improved health, safety and environmental performance;
- optimized return on investment and/or growth;
- enhanced long-term planning confidence and performance sustainability;
- the ability to demonstrate best value-for-money within a constrained funding regime;
- evidence, in the form of controlled and systematic processes, to demonstrate legal, regulatory and statutory compliance;
- improved risk management and corporate governance and a clear audit trail for the appropriateness of decision taken and their associated risks;
- improved corporate reputation, the benefits of which may include enhanced shareholder value, improved marketability of product/service, greater staff satisfaction and more efficient and effective procurement from the supply chain;
- the ability to demonstrate that sustainable development is actively considered within the management of the assets over their life cycles.

The definitions of the different phases differ somewhat depending on the approach taken, being it process driven (such as in Hastings, 2010) or asset oriented (such as in Brent et al., 2005)

The first author (Hastings, 2010) identified the following main stages in the life cycle:

- identification of business opportunities or needs;
- asset capability gap analysis and requirements analysis;
- pre-feasibility analysis, physical and financial – options selection;

- feasibility planning, physical and financial – for selected option;
- acquisition, development and implementation;
- operation, logistic support and maintenance;
- monitor and review;
- disposal.

The first four phases underlines the linkage between business strategy and asset management strategy (as already discussed in the previous section).

Brent et al. (2005) developed the concept of asset life cycle management starting from Blanchard and Fabricky (1998)

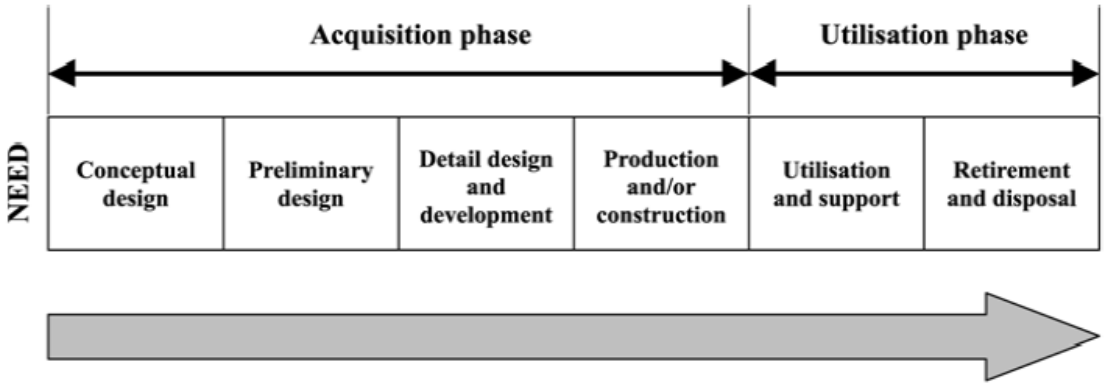

Fig.2.10 Life Cycle phases of process asset system from Blanchard and Fabrycky, 1998

Fig.2.10 indicates two distinct phases, namely the acquisition phase and the utilization phase. In industrial practice, with specific reference, for example, to the process industry, the management responsibility normally changes hands from one phase to the next. In particular, either the research and development or the technical department may take full responsibility for the acquisition phase, handing over to the operations department for managing the utilization phase.

The challenge in managing the entire asset life cycle effectively lies in the fact that costs are isolated and addressed in a fragmented way through the various stages. Referring to the Brent et al. (2005) life cycle model, during the acquisition phase the emphasis is on implementing a technology within the boundaries of the approved budget and prescribed time frame, while ensuring that the facility acquired conforms to the technical specifications. The primary drivers of the utilization phase are instead

the associated costs of product distribution, spares and inventory, maintenance, training, etc.

In general, during the whole life cycle, costs are collected in order to develop a life cycle cost (LCC) analysis. Costs invested at the beginning (CAPEX) have impact on costs expected, and then observed, during the asset utilization (OPEX) (Fig.2.11).

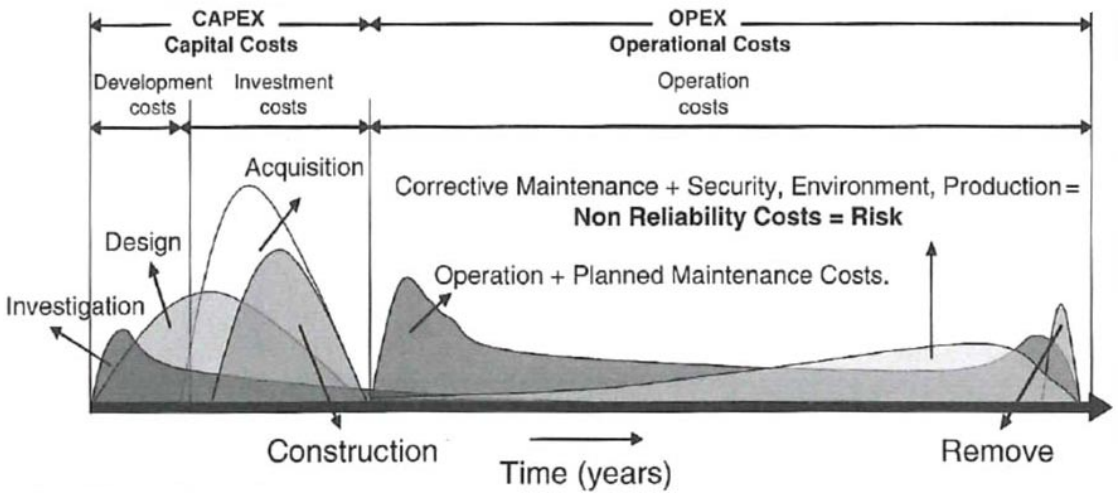

Fig.2.11 Life cycle cost analysis from Crespo et al. (2009)

Therefore, life-cycle cost analysis can support management decisions in order to identify the option (new investment, repair,..) with the lowest life-cycle cost that allows to satisfy stakeholders' requirements.

2.3.4 Risk Asset Management

Asset management is often viewed also as an integrated approach to balance costs, performance and risks during the asset life cycle.

There are different categories of risks to be considered and PASS 55 identifies the followings:

- physical failure risks, such as functional failure, incidental damage, malicious damage or terrorist action;
- operational risks, including the control of the asset, human factors and all other activities which affect its performance, condition or safety;

- natural environmental events (storm, floods,..);
- factors outside the organization's control, such as failures in externally supplied materials and services;
- stakeholders risks such as failure to meet regulatory performance requirements or reputation damage;
- asset related design, specification, procurement, construction, installation, commissioning, inspection, monitoring, maintenance, refurbishment, decommissioning and disposal risks as appropriate.

Risk identification assessment and control are then important functions for proactive asset management. Knowledge of risks is an important step in asset risk management, but is not enough. The next step is to know what to do with these risks (Korn, 2008).

The purpose of Risk Asset Management functions is to understand the cause, effect and the likelihood of adverse events which may occur while an asset is managed. Indeed, the risk assessment is important in different areas of the organization and became fundamental in Asset Management Projects (PAS 55, 2008).

While the range of risks in a modern plant is enormous, fortunately not all are of equal significance and usually only a relatively small percentage, about 10% (Healy, 2006), requires the highest level of risk management to control them. Only after the evaluation they will be identified and this means that the criticality assessment has to be carried out for all assets and systems in the area of interest before the 'Critical Few' can be identified from the rest (Healy, 2006). Criticality assessment is a structured methodology that provides a proactive approach for the assessment of risks in the organization.

Regarding the risk management process, there is no standard terminology. Herder and Wijnia (2012), analyzing risk management in Infrastructure Asset Management, identified the following three phases in the risk management process:

- establishing the context;
- risk assessment;
- risk treatment.

The ISO standard on risk management (ISO 31000: 2009) uses risk assessment as the building of risk identification, risk analysis and risk evaluation, whereas COSO

framework (COSO, 2004) separates event identification from risk assessment (a bundling of risk analysis and risk evaluation). However, the steps are very similar, even though the terminology differs.

Also in PAS 55, there is explanation of a systematic approach to evaluate risks, made of the following steps:

1. classify assets: prepare a list of assets and their components;
2. identify potential risks;
3. identify the risk controls that exist;
4. estimate the likelihood and consequences for each potential risks;
5. determine the tolerability of the risks, in other words, decide if planned or existing controls are sufficient to keep the risk under control and to meet any legal, statutory and other asset management requirement.

Focusing on risk assessment, there is no one method in literature. There are various techniques varying from the 'Wild Guess' to the fully 'Quantitative Risk Analysis'. The more common systematic approaches to identifying and representing Criticality include 'Qualitative Assessments', 'Semi-Quantitative assessments' and 'Quantitative Assessments' (Healy, 2006).

Quantitative assessments are based upon historical data to 'calculate' the rankings assigned to the equipment or failure mechanisms being assessed. These calculations typically include probability of failure and cost of each failure event. Obtaining the necessary data can be very difficult and often the data has to be pre-processed to get it into a form suitable for the analysis and any pre-processing must be understood and carefully carried out to prevent distortions of the final outcomes.

In some cases, especially for assessing the consequences for safety and environmental failure mechanisms, it is not easy the quantification of the risks and qualitative and semi-quantitative represent the only possible approaches.

In this concern, It is important to select an assessment approach in keeping with the needs of the organization because the use of a too basic approach can result in insufficient resolution while an overly detailed approach can increase the cost and time for the assessment and result in a lot of redundant or unnecessary data being generated.

Depending on the level of detail included in the Criticality Analysis, the results allow many Asset Management decisions to be based on objective criteria and they also provide an audit trail for future review and updating (risk treatment step).
Some of the applications of the criticality analysis results, identify by Healy (2006), include the following:

- Provide a common communication tool;
- Process system design;
- Redundancy – equipment and systems;
- Maintenance programs;
- Work management based on known risk;
- Identify spare parts requirements;
- Target maintenance budgets;
- Identify training requirements;
- Identify skill based risk;
- Quantify the maintenance commitment CSFs, KPIs (critical success factors, key performance indicators);
- Provide a basis for system modeling;

During the risk treatment the option that provide the best net benefit unit of employed resource should be chosen. A practical approach is to monetize the effects on all value and perform a net present calculation but very often mitigation measures have a timing option, so it is needed an integrated approach that takes into account both cost and time of the actions (Herder and Wijnia, 2012)

2.4 Data, Information and Knowledge in Physical Asset Management

Bohn (1994) provides definitions to distinguish between data, information, and knowledge. *Data*, derived directly from monitoring or sensing the measured level of variable in the form of a stream of measurement, is transferred to a database, where it is stored in a form customized for the users and suitable for limited analysis. *Information* is data which is organized or given structure, and gives the current or past status of some part of the system and may be used for optimization and decision analysis studies to produce knowledge. *Knowledge*, as information combined with experience, context, interpretation and reflection permits making predictions, casual associations, or prescriptive decisions about what to do. Knowledge accumulates in

programs, technologies, roles, activities, software, skills as it is articulated and becomes formalized.

Data, information and knowledge in PAM is further analyzed in next subsections, looking at three different perspectives: asset management data life cycle, information flows and asset knowledge.

2.4.1 Asset management data life cycle

The pressure on cost reduction increased the importance of monitoring performance, above all maintenance performance. It is widely acknowledged that it is necessary to support maintenance staff by supplying them with accurate and up-to-date information regarding maintenance tasks and recent history.

In order to do this, it is important that the necessary data is captured, stored and presented in an appropriate way. Asset management and condition data can be captured either manually or with sensors but this potential wealth of information must be effectively managed if it is to be of use (Baglee et al., 2012).

Baglee et al. (2012) identify a cyclic process in managed data:

- Data Gathering
- Data Storage
- Data Analysis
- Data Presentation

Data gathering: collecting data is crucial for both scheduling maintenance and for assessing the performance of maintenance regime. This can be done through manual inspection or online sensors, and may regard also cost data for both maintenance and repairs followings failures, usage statistics and downtime costs resulting from both maintenance and repairs.

Many condition sensors are available ranging from simple temperature probes, vibration sensors, and pressure transponders to advanced systems such IR spectrometers for automatically measuring the condition of lubricating oil. Other important condition monitoring technologies include vibration analysis, acoustic emission analysis, thermography and mechanical stress measurement. These condition-specific techniques can be supplemented with the analysis of other general, functional characteristics of the equipment, such as flow rates, temperatures and

pressures. Furthermore, energy consumption is increasingly finding applications as an indicator of condition.

These automated techniques can also supplement manual data collection using devices such as PDAs (Personal Data Assistant) and hand held data collectors. The increased memory capacity computational power of mobile phones will lead to them finding application in this area (Fumagalli et al., 2010)

Data storage: once data are collect, it is important to store and manage them in a manner which makes it easily accessible and which allows the required data to be accessed efficiently when required.

Database systems offer many advantages in the field of asset management and maintenance in terms of security and data accessibility. Database systems are then an essential part in order to achieve data storage, and may find many different forms in maintenance application, ranging from general purpose tools (i.e. tools to develop data bases commercially available in PC platforms, such as e.g. Microsoft Excel and/or Access) to being core part of so called CMMSs (Computerized Maintenance Management System) or software modules of more general ERP systems.

To better integrate different systems needed in maintenance application, ranging from shop-floor / equipment to business level, a number of standards has been proposed. Such standards are the main background in order to develop systems' interoperability in maintenance, they may be both generic (such as e.g. XML) and specific standards (MIMOSA for condition based maintenance, …).

Data analysis: analysis of data are fundamental to identify maintenance areas where improvements are possible or necessary.

Several methodologies exist to maximize the performance of a maintenance regime based on an analysis of the performance of the assets and the existing maintenance regime. The primary methodologies are Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM), with variations being developed to suit individual organizations. TPM/RCM include then different methods for data analysis such as, e.g., histograms, Pareto diagrams and RCA (root cause analysis) originally used in TPM, Weibull analysis and RBD (Reliability Block Diagram) promoted in the frame of RCM.

Data analysis is also important in terms of extracting meaningful information from raw sensor data using statistical techniques. The goal of any statistical analysis is in fact to uncover facts. Various tools are available for data processing and analysis to this end. The most widely used techniques are Artificial Neural Networks, Statistical Learning and Probabilistic Modeling (Baglee et al., 2012). Most fault detection systems function by studying the relationship between various sensor readings and using some form of model to detect abnormal behavior.

Data presentation: presenting data in a convenient and appropriate way is vital in ensuring that asset management systems are used effectively and provide a return on their investment.

Having a good data presentation system means providing the correct data to the correct personnel. For example, management personnel require a high level overview indicating current performance across an appropriate reporting period while shop-floor maintenance engineers require current data relating to the operations assets which are their responsibility.

PDAs, other mobile devices (such as smart phones) and Dashboard Interfaces are very useful tools for this aim, i.e. in order to achieve a customized presentation of data/reporting to the user. In particular:

- PDA technology supports the transfer of data between the user and a central maintenance database system. The role of the PDA is to provide a user-friendly, comfortable and powerful mobile computing device for dealing with different types of data processing and maintenance activities.
  PDA can be used in a different way, relating to the needs of the users. For example, technicians can follow the onscreen instructions step-by-step to complete a maintenance task. Even in poor conditions where no network connection is available, PDAs will become more useful since a compact database can be pre-stored inside the PDA's internal memory or memory stick.
- Evolution of PDA and mobile phone technology are smart-phones, that are available at relatively low cost and offer the ability to run easily-written software. Furthermore they are increasingly equipped with high level systems such as GPS receivers and broadband connectivity. Smart-phones also feature calendar and organizer systems which can be integrated with bespoke

software. These features, coupled with steadily growing memory capabilities, make smart-phones the likely replacement for PDAs as mobile maintenance management tools, especially in applications where remote maintenance is required due to their mobile connectivity.

- Dashboard system is an "*user interface that is to be easy to read*" (Wikipedia, Dashboard (management information systems), 2012). It has been a well covered topic in many areas of decision support. These systems provide, for example, management personnel with only the most essential information required for senior managers to assess. Also technical personnel may find the required data presentation: simple graphical displays are used in order to illustrate and present, e.g., power consumption, maintenance and condition monitoring data with click through access to greater detail and analysis as required.

Fig.2.12 summarizes the previuos concepts.

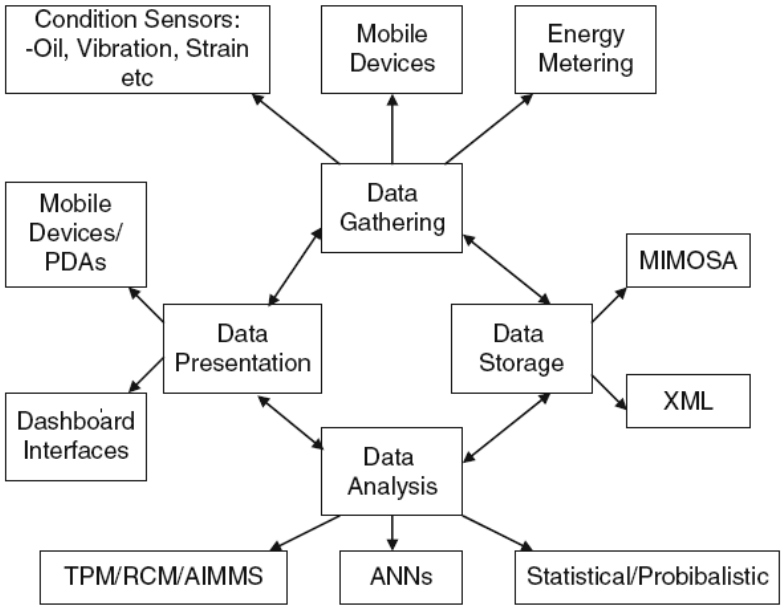

Fig.2.12 Asset Management tools by position in data lifecycles from Baglee et al., 2012

2.4.2 Information Flows In Physical Asset Management

Asset lifecycle management involves significant amount of acquisition, processing, and analysis of information that enable a variety of lifecycle aspects such as planning,

design, maintenance, rehabilitation, and disposal/refurbishment or replacement of assets. Information Systems (IS) become then necessary in order to integrate the cross functional information.

IS, in asset management context, have not only to provide support for decentralized control of maintenance tasks, but also to act as instruments for decision support, for example, in order to solve trade-offs between deferred maintenance and preventive maintenance, between short-term fixes and long-term solutions.

As we said in the previous sections, asset lifecycle management could be termed as a combination of decisions aimed at strategic, tactical, and operational levels with varying degrees of time frames. In terms of information flows, asset management represents a two-way process, where downstream information flows define strategies at each stage of asset lifecycle, and upstream information flows provide feedback on effectiveness of the implementation of these strategies (Fig.2.13).

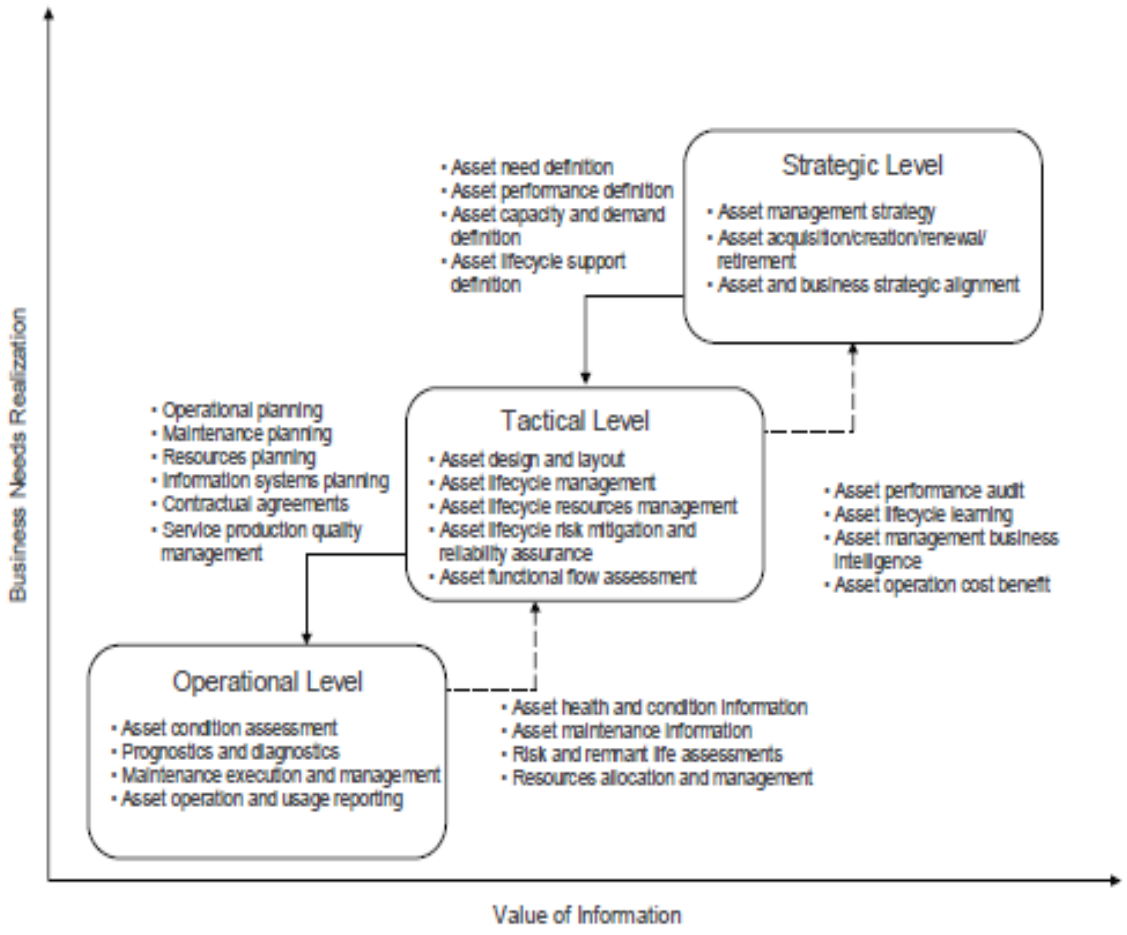

Fig.2.13 Downstream and upstream flow of information (from Haider, 2008)

Information in PAM acts as strategic translator as well as strategic enabler (Haider, 2008). In the first view, information enforces decisions to manage asset lifecycle, whilst, in the other view, information enables decisions on how to best mange the asset lifecycle.

The strategic layer takes a total cost of ownership perspective and is concerned with the decisions such as asset design and refurbishments, asset demand management, performance definition, planning of performance and capacity, and asset lifecycle supportability design. These decisions depend upon the quality and availability of information on asset performance, cost and efficiency audits, and sustainability of the service and delivery potential through asset operation.

The other two layers work towards compliance of performance standards defined by strategic layer with a longer time horizon. Tactical layer has a proactive scope and is focused on establishing procedures and plans aimed at developing lifecycle operational, maintenance, and service quality levels, risk management initiatives and asset and lifecycle processes reliability modeling, through definition of arrangements such as information systems, and third party contractual agreements. This layer is the most important layer in terms of IS, as the overall process of operational asset management is driven from this layer. The tactical layer specifies the types of, and the interaction between different IS employed to facilitate asset lifecycle management. Significance of this layer underscores the need to integrate asset management systems to enable an integrated view of asset lifecycle as well as to provide a consolidated conduit of information to help enterprise planning and risk management.

The operational layer represents the functions necessary to keep the assets up and running to near original condition. The focus of this layer is to manage asset workload, provide assessments on asset operation and condition, diagnostic ability to detect failure conditions, alarm and notifications generation, and maintenance scheduling and execution. The objective of the operational layer is to provide an ongoing snapshot of asset health and operating conditions to tactical and strategic layers. Successful utilization of IS at this layer, therefore, depends upon the speedy availability, quality, and interoperability of information.

It is clear that the IS have different roles in asset lifecycle management, ranging from simple record keeping tools to strategic decision support aids. However, the success of IS requires different features:

- appropriate hardware and software applications;
- quality, standardized, and interoperable information (because interoperability is required across the different phases of the asset life cycle);
- appropriate skill set of employees to process information; and
- strategic fit between the asset lifecycle management processes and the IS.

2.4.3. Asset Knowledge

According to Hastings (2010), Asset Management depends on the knowledge about the organization's assets, in terms of both current equipment, business role of the assets and future business prospects. Indeed, Asset managers need to have a practical working knowledge of the major assets at a management level so as to be able to make sound business decisions. They need to be aware of the components constituting the asset system and how each of them impact on the capability of the system, and they also have to keep systematic track of the changes to equipment configuration, such as technical upgrades and regulatory compatibilities.

A summary of points of knowledge, defined by Hastings, which an asset manager may need to have is shown below in a number of managerial questions:

1) What asset have we got?
2) Where are they located?
3) What is the business significance of our major assets?
4) What is the profit and loss position of our major assets?
5) What is our asset utilization including peak load and seasonal factors?
6) Are there gross imbalances – that is, major shortages, surpluses or misallocations of equipment or personnel?
7) What is the condition of each major asset?
8) Are reliability or availability issues significant?
9) How much longer can specific assets last?
10) Are there significant risks?
11) Are maintenance costs a significant factor?
12) What asset related developments and market opportunity exist?
13) What has the market got to offer in terms of assets that we might usefully acquire?

Vanier (2001) identified the following six questions which can drive the assessment of the current asset condition of the organization, so creating asset knowledge:

- What do you own?
- What is it worth?
- What is the deferred maintenance?
- What is its condition?
- What is the remaining service life?
- What do you fix first?

More insight is provided in the remainder of this section.

1. What do you own?

The first question to be answered relates to the physical area of responsibility of an organization. Administrative change such as restructuring, amalgamation or downsizing makes it difficult to document the full extent of an organization's portfolio.

Tools in the IS (see previous section 2.4.2 focused on this topic) which can help to answer the question are: Geographical Information Systems (GIS), CAD systems and relational database management systems which provide accurate pictures of the extent of an asset management portfolio. One such tool that is typically used to record what assets are owned is a Computerized Maintenance Management System (CMMS). There is a large selection of “fully commercialized” CMMSs available; many of these systems are relational database applications that can be adapted to meet the data handling needs of asset managers. For example, any number of CMMS applications can manage work orders, trouble calls, equipment cribs, stores inventories and preventive maintenance schedules, and many programs include features such as time recording, inventory control and invoicing. The CMMS’s capability to store inventory data is very high, but their capacity with respect to life cycle economics, service life prediction and risk analysis is considerably less sophisticated.

2. What is it worth?

Once an organization identifies the extent of its portfolio, the next question to be answered is "what is the asset value?”. Unfortunately, it is not a simple matter of providing numbers for each asset, as assets may consist of many components with their own individual values, they may have historical values on record, or there may be approximations based on unit areas or volumes.

In particular, there are different terms to describe the “value” of an asset: historical value, appreciated historical value, current replacement value, “performance in use” value, deprival cost and market value. But many organizations do not store the “value” of that asset in their IS, but only the cost of installation or replacement. Nonetheless, asset managers require both value and cost in order to make educated and informed decisions about maintenance and renewal.

One of the analysis tools most utilized to understand the “value” of an asset is the Life cycle costing (LCC). It is useful for comparing different options, for example, in order to evaluate if it is more expensive maintaining an asset or replacing it with a new investment, or also to decide between two possible investments one with lower cost of installation and another one with lower cost of utilization. But LCC, to be properly applied, may require better information on the different terms of “value” of an asset.

3. What is the deferred maintenance?

When the calendar comes to a maintenance scheduled event, we cannot stop at this event only by considering the annual costs. It must be considered the likely effects of postponing an operation to the next year. This is important because if the maintenance is not completed in year one, then the costs of maintenance, repair or replacement are significantly higher in subsequent years.

Typically, CMMS tolls can help to understand these effects studying trends and other information stored in it, for example, data about the repair dates, repair scope, labor costs, contract specifications and drawings.

4 What is its condition?

Often, in order to understand better the condition of an asset, a Condition Index (CI) is calculated including different factors, such as the number of defects, physical condition and quality of materials or workmanship. During this phase it is important to make forecasts on the future CI, through benchmark not only with different assets, but also for the same asset at different time.

5 What is the remaining service life?

After the extent of the asset portfolio is established, along with its value and technical condition determined, the asset manager must also be able to establish the remaining service life of the assets: this is needed in order to calculate the life cycle costs for alternative maintenance, repair and renewal strategies.

6 What do you fix first?

Only after having found the answers to the previous questions it is now possible to determine what issues need to solve first.

In the organization there are a lot of assets and each of them needs maintenance, needs parts, has own life and after this period needs to be replaced.

The resources, however, are limited and asset managers have to recognize, through the previous answer, what are the priority. For example, through the second question "what is it worth?" they understand the importance of the specific asset within the system, thanks to the third question it is possible to evaluate what impact would have on costs if the specific asset is not included in the priority of the current year. Overall, the previous steps try to understand if assets are in bad condition, are hazard, are slated for renewal.

In addition with the information found before, there are a number of socio-technical challenges to be taken into account, before finalizing an answer on the "what to fix first".

Financial Versus Technical Challenges: Asset managers have a constant technical challenge to weigh the costs of maintenance, repair or renewal versus the technical and functional benefits of implementing a solution.

Planning Horizons Challenges: Different authors identify three planning horizons to illustrate the conflicting nature of long-term decision-making for asset managers: operational, tactical, and strategic. The operational planning horizon is identified as that within the two-year time frame; the tactical planning is the two to five year time horizon, whereas the strategic planning is planning beyond the five-year term.
Often managers try to improve performances in the short term, see more certain, at the expense of the results in the long-term. This is because in the strategic planning horizon there are a lot of factors to consider, most of them to estimate.

Network Versus Project Challenges: To maximized the performances of a single asset needs resources that are subtracted from other projects. Asset Management is an integrated and systematic approach which try to optimize the whole portfolio of project and role of asset manager is to share resources among the various projects in order to obtain a global optimum for the asset portfolio under his/her responsibility.

Concluding, it is clear that, in order to achieve an effective PAM, Asset Knowledge has to be operated spread through different planning horizons, considering a variety of technical and business issues: to this end, it is fundamental obtaining the proper information, hence the IS has a strategic role for supporting the Asset Knowledge creation as well as its maintenance.

2.5 Asset Performance Assessment

Asset performance management is a multi – disciplinary management process, which provides a critical support for heavy and capital – intensive industry by keeping the assets like machinery and equipment in a safe operating condition. Managing the asset performance is critical for long-term economic and business viability. Asset performance assessment is a complex issue involving multiple inputs and outputs besides various stakeholders' dynamic requirements. Lack of integration between various stakeholders and their changing requirements in strategic asset performance assessment is still a major issue for industries (Parida, 2012).

From some time there has been considerable interest in performance measurement. It is established that companies using an integrated balanced performance measurement system perform better than those not measuring their performance (Lynch and Cross, 1991).

From literature, it emerges that measurement systems must reflect the context and the objectives of the organization. The nature and the design of performance measurement systems has been changing during these years to ensure that they reflect the environment and the strategies of organizations (Kennerly and Neely, 2003). During the last two decades, competitive and dynamic business environment requires the asset utilization and performance optimization throughout their life cycle.

In order to know the efficiency and effectiveness of asset management, the assessment of asset performance has become an integral part of the business today (Parida, 2012). The introduction of technological instrument such as embedded and wireless sensors, automated controls and data analysis management has allowed to overcome the barriers of distance, to transfer real time date and, hence, to develop new performance assessment systems (Toran et al., 2000). Again the IS is a fundamental lever for the development of performance assessment systems

2.5.1 Issues related to Key Performance Indicators

The management of the organization needs to convert the corporate strategy and objectives to the specific objectives of different hierarchical levels of the organization. The asset performance needs then to be measured and managed for achieving the objectives.

In order to achieve the asset performance objectives, derived from corporate objectives and strategy, critical success factors are normally identified and, starting from these, Key Performance Indicators (KPIs) are developed for measuring the assets performance. KPIs are periodically measured and also used in benchmarking activity and to send feedback improving the assessment performance systems (Parida, 2012).

For many asset intensive industries, the operation and maintenance costs of assets are a significant portion of the total cost. Further, breakdowns and downtime have an impact on the plant and asset capacity, product quality, and cost of production, as well as on health, safety and environmental issues (Parida, 2012). Hence, there are a lot of research in literature concerning KPIs maintenance performance.

Galar et al. (2011) identified the following issues about KPIs Maintenance performance and their challenges/problems for implementation:

1) Too much data and little information: The acquisition of data has become relatively simple and cheap through the introduction of modern and powerful hardware systems and software. But having too much data could be useless if they are not understandable by the users.
2) The number of performance indicators, ownership of the data and the aspects to be covered are too high: hence, the number of indicators used for each figure, or department, should be limited by identifying key features or "key factors". On the other hand, scorecards with huge quantities of indicators without user or defined personal responsible provide only hinder to the work for which they are made.
3) Clear objectives and measures: There are situations where departments within the same company have conflicting interests in relation to the maintenance of their equipment. The purpose of the objectives is to ensure that departmental efforts are aligned with business needs. The objectives should be transmitted in a downward cascade, including all departments, and

subsequently taking appropriate steps according to the measures adopted by the selected sensors, ensuring that everyone is going in the same direction (i.e. aligned with business objectives / strategy).

4) Time lag between action and monitoring results: Sometimes there is a delay between a policy change and the appearance of clear and apparent results associated (or expected) with that change. A second delay can be found between the appearance of results and the time taken for the measurement. This should be taken into account when assessing asset performance.
5) The cost and reasons for data collectors: The success of any measurement system is based on the method used for data collection. Poor or incorrect data entered into a reporting system will result in poor and little value. Human factors involved in the collection of data are an important aspect, as the data collected by personnel are closely related to indicators of their ownership and responsibility, towards achieving their own objectives. The technicians and operators will collect data only if they believe it is worthwhile and the results are made available for free consultation and use. If the time passes and data have not been used for anything, have been forgotten and feedback produced by them has not been transmitted through good communication, people will inevitably feel a waste of time, and reduce their effort and/or attention to data collection.

Asset performance, which include KPI maintenance performance and other aspects (i.e. business and technical aspects), can be applied all these challenges. In fact, the system of asset performance measurement should cover all processes related to it within the organization.

2.5.2. Frameworks of Key Performance Indicators

In literature, one can be find a lot of authors who define a set of indicators divided into different groups, aggregations. For example, Wireman (1998) divided indicators in corporate, financial, efficiency and effectiveness, tactical, functional performance; while Càceres (2004) segmented maintenance indicators according to the organization's area of influence, due to interactions of the maintenance department with finance, human resources, purchasing and, of course, production to achieve corporate objectives.

Another interesting approach is proposed by Tsang's (2002), in which the author adopted the scorecard method developed by Kaplan and Norton. It designs the maintenance performance measure using the following four perspectives:

- Financial (the investor's view)
- Customers (the performance attributed valued by customers)
- Internal process (the long-term and short-term means to achieve financial and customer objectives)
- Learning and growth

Tsang (2002) considers that by using the Balanced Score Card, the company could link the maintenance strategy with the overall business strategy and develop performance measures for maintenance that are linked to the organization's success.

Kumar et al (2011) extended Tsang's model, considering also health, safety, security and environment and employee satisfaction to make the MPM (Maintenance Performance Measurement) system balanced and holistic from the organizational point of view.

In order to help managers in their decision process there must be an interconnection between the different indicators (Galar et al., 2011).

According to Mitchell et al. (2002), a hierarchy of different parameters, all linked to business goals, is vital for the success of a program to manage corporate physical assets.

Also Grenčík and Legat (2007) analyze the consistency of the indicators and their management classification levels. To select the relevant indicators, the first step is to define the objectives at each level of the company. At the company level, the requirement is to determine how to manage maintenance to improve overall performance (profits, market shares, competition, etc.). At the level of production, performance factors which have been identified through prior analysis are more important; these include improved availability, improved intervention costs, safety, environmental preservation, improvements in maintenance costs, value inventory, contracted services control, etc.

Parida and Chattopadhyay (2007) developed an APA (Asset Performance Assessment) framework in which considered different set of indicators and link them

with the needs to define a hierarchy, considering three levels: strategic, tactical end operational, as we can see in Fig.2.14.

Level-1 Strategic/Top Management	Level-2 Tactical/Middle Management	Level-3 Operational/ Functional	Multi-Criteria
- Value added productivity - Overall plant Effectiveness - Overall sub-process effectiveness - Overall equipment effectiveness (OEE)	- Production rate (ton/hour) - Quality rate - Availability - Overall equipment effectiveness (OEE)	- No of equipment Failures - No of process failures - Downtime	Asset Indicators
- PM:CM percentage - Reduction in maintenance days - Maintenance cost/unit (MC) - System reliability - Energy saving percentage	- Failure frequency - Emergency repair rate - Failure severity rate - Start up after shutdown - PM rate & CM rate - Energy consumption	- MTBF - MTTR - No. of minor stops - Maintenance delay - Response time for maintenance	Operation & Maintenance Indicators
- Maintenance budget - ROMI - Operational budget	- Unit maintenance cost - PM & CM cost - Reduction in spares - Production cost/unit	- Maintenance cost/unit - Reduction in spares - Production cost/unit	Cost Indicators
- No of accidents - No of compensation cases - No of HSE complaints - No of HSE legal cases	- Accident frequency - Accident severity rate - No of incidents - Workplace noise level -No of pollution discharges	- No of accidents - No of incidents (not requiring time-off) - Work place noise level	HSE Indicators
- No of innovation carried out - No of improvement suggested	- No of PM training days -Cost saving in innovation	-Time spent on training - No of improved topic	Learning & growth
- No of Customer complaints - Customer retention rate	- Customer satisfaction rate - Quantity returned - Customer retention rate	- Customer complaint rate - Quantity returned	Customer satisfaction
- Employee complaints - Employee retention	- Employee complaints - Employee satisfaction	- Employee complaints	Employee satisfaction

Fig.2.14 Multi-criteria hierchical MPA framework for Engineering Asset (adapted from Parida and Chattopadhyay, 2007). HSE = Health, Safety and Environment; ROMI = Return on Maintenance Investment; OEE = Overall Equipment Effectiveness; MTBF = Mean time between; MTTR = Mean time to repair

Concluding, all the above mentioned references provide examples of Frameworks of KPIs proposed initially for a maintenance scope, but soon extended in order to have a business perspective, and to be finally claimed as frameworks for engineering asset performance assessment.

2.5 Concluding Remarks

This chapter has provided a wide overview of PAM, to prepare the background for the establishment of a maturity assessment for PAM.

As a result of the chapter, it can be synthetically stated that, when talking about PAM, the following topics are relevant for assessing how PAM is developed (hence mature) in a company: the organization, considering both PAM function, roles of personnel and cultural aspects, the Asset management decision making framework and needed methodologies such as those enabling Asset Life Cycle Management and Risk Asset Management; the Information System for supporting Asset management; the Asset Performance measurement. The maturity assessment for PAM should consider all these topics

Chapter 3. Maturity Assessment Methodology

In this Chapter, the methodological aspects of this research – related to the maturity assessment – are presented.

The work starts from the comparison between two models. The first one is the Maintenance Maturity Model, developed by TeSeM Observatory (on Technologies and Services for Maintenance) of School of Management of Politecnico di Milano and the second one has been developed by a research group at Delft University of Technology (TUDelft), Faculty of Technology, Policy and Management (TPM).

In Section **1** a short introduction to maturity models is provided, focusing on benefits of their adoption. Therefore, in Section **2**, the Capability Maturity Model Integrated (CMMI) methodology is quickly presented, describing its two possible representations of maturity. In Section **3** we analyze the Maintenance Maturity model developed by TeSeM Observatory – based on the CMMI methodology –, while in Section **4** the TUDelft Model – also based on the CMMI methodology – is analyzed. Afterwards, a comparison between the two models is developed, in Section **5**. In the last Section **6**, a third model, also used as a support in developing the new one proposed in this thesis, is finally presented.

3.1 Introduction to maturity models and their benefits

The use of maturity models provides a number of advantages. Volker et al. (2011) summarize them, in general, in the followings.

- First of all, maturity models provide a normative description of good practices. That is, the maturity levels set an ideal standard that organizations can strive for.
- Another benefit of maturity models is that they are a discussion tool for engaging interviewees and enable reflection on the current status of an organization. The resulting identification of strengths and weaknesses can act

as a framework for prioritizing actions and can help raising awareness about a particular strategic process among the employees and board members.

- Finally, maturity models can be used to benchmark (parts of) organizations.

Van der Lei et al. (2011) mention the positive link between the implementation of PAM standards, such as PAS55, and the maturity level of an organization. This implies that increased attention for quality improvements and strategic asset management could improve performances in a company, just as much as a maturity model or other kinds of standards could contribute to business results.

3.2 The Capability Maturity Model Integrated methodology

Both TeSeM and TUDelft models were developed basing on the CMMI (Capability Maturity Model Integrated) methodology.

The first version of a capability maturity model (CMM) was developed by the Carnegie Mellon University as a tool to objectively assess the ability of contractors in performing a project. It was based on data from software projects for the U.S. department of Defense and a process maturity framework for software processes. Gradually, it has been extended as an appraisal method into a broader array of areas, such as the IPD-CMM (Integrated Product Development Capability Maturity Model), P-CMM (People Capability Maturity Model), SW-CMM (Capability Maturity Model for Software), SE-CMM (Systems Engineering Capability Maturity Model), SA-CMM (Software Acquisition Capability Maturity Model), and CMMI (Capability Maturity Model Integration).

A maturity model can be viewed as a set of structured levels that describe how well different processes of an organization are able to produce the required outcomes in a reliable and sustainable way.

There are two possible **representations** in CMMI approach (Minzoni, 2004):

- *Staged Representation (SR)*: 5 Maturity Levels (MLs) are defined, and they are related to the whole activity that must be evaluated; for each of them, a few Process Areas (PAs) are defined, and they have to be improved to reach the specific ML. So, if a generic firm is at a level 3 of maturity, it has to improve a set of predefined PAs in order to pass to level 4. This means that

this representation provides a predefined roadmap for improvement, in which every stage/ML contains a set of PAs indicating where to focus in order to make company work better.

- *Continuous Representation (CR)*: 6 Capability Levels (CLs) are defined, instead of MLs; a CL represents a measure assigned to a lone PA; in this way, maximum flexibility for firms to choose which processes to point at is provided. The adjective "continuous" means that there are no stages in which to focus on different goals, and procedures to follow are organized in order to support the development of every single process area. In this representation, unlike in the staged one, goals are not specifically defined. Here, every process has a different capability level, and the whole of them make up a so-called Capability Profile.

3.3 The TeSeM Maintenance Maturity Assessment Model

The purpose of this model (Macchi et. al, 2011) is to analyze how maintenance practices are currently set up in an organization, especially focusing on how new practices were developed thanks to the advancement in the use of ICT tools/devices for diagnostics, prognostics and maintenance engineering.

The model was developed based on the CMMI methodology, in particularly the continuous approach was preferred because the authors suppose that there is not a pre-defined roadmap in maintenance management (considering also the possibility to have different good practices in different company's sectors and sizes). Continuous Representation offers the maximum flexibility for prioritizing process improvements and aligning them with the business objectives. Henceforth, the authors proposed a "modified" continuous representation in which they defined five maturity levels (instead of six capability levels) with a similar meaning of the "original" CMMI model. In particular, maintenance is analyzed considering a number of Process Areas (PAs), as suggested by the CMMI methodology.

More specifically, the TeSeM model aims at evaluating technological, organizational and management aspects in maintenance, defining three synthetic maturity scores summarizing company's behaviors. As a final outcome, the maintenance maturity is assessed both as a synthetic index, General Maturity Index (GMI), and as a set of

component indexes accordingly with PAs identified, Managerial (MMI), Organizational (OMI) and Technological (TMI).

- Managerial Maturity Index (MMI) assess al the PAs concerned with the planning and control cycle.
- Organizational Maturity Index (OMI) refers to all those PAs concerned with knowledge management and improvement of internal and external relationship (within the maintenance internal structure and with parties external to the maintenance department, i.e. with other enterprise functions or third parties).
- Technological Maturity Index (TMI) takes into account all the PAs related to the support of information systems, ICT tools, diagnostic/prognostic tools, maintenance engineering tools: the main concern is to assess how tools/devices are being adopted in the company's practices.

Related questions were defined for each PA in a survey questionnaire. For every question, its related scores are defined according to the maturity scorecard, and thus interviewing the maintenance manager of a firm it is possible to calculate all the maturity indexes. The GMI is obtained multiplying the three indexes (GMI = MMI x OMI x TMI).

In Table 3.1 is shown the scorecard defining the scale of the maturity levels

Maturity Level	Description
ML 5 Optimizing	Process is managed by ensuring the continuous improvement; causes of defects and problems in the processes are identified, taking actions in order to prevent problems from occurring in the future
ML 4 Quantitatively Managed	Process performances is measured, and causes of special variations are detected; quantitative analyses are conducted, indeed a good balance is reached between the quantitative and qualitative analysis; process management is fulfilled thanks to organizational responsibilities and fully functional technical systems
ML 3 Defined	The processes is planned; semi-quantitative analyses are done periodically to define good practices/management procedures; process management depends on some specific constraints for the for the organizational responsibility or the technical systems
ML 2 Managed	The process is partially planned; performance analysis is mostly dependent on individual practioners' experience and competences; process management is weak because of deficiencies in the organizational or in the technical systems
ML 1 Initial	The process is weakly controlled, or not controlled at all

Table 3.1 Maturity Levels in TeSeM model

From the questionnaire and the scores assigned to the answers included in the questionnaire, a matrix (Table 3.12) can be defined in which the maturity levels are decomposed in each component index. This matrix does not change the substance of the original TeSeM Model but it represents a useful presentation for a synthetic perception of the method and it helps the comparison with the TUDelft Infrastructure Maturity Model, which will be described in section **3.4.**

	Maintenance Technological Maturity	Maintenance Management Maturity	Maintenance Organizational Maturity
OPTIMIZING	Continuous improvement leads changes in plan and practices. RCM is continuously revised and improved.	Preventive plans are developed in accordance with the assessment of previous performance in order to follow continuous improvement.	There is an autonomous team for CMMS data. HSE policies are developed by a no subject team. Cooperation between maintenance and other function, maintenance is a support for the whole enterprise. TPM is developed as a standard, team building is encourage. Partnership with contractors is preferred.
QUANT. MANAG	All activities are made with enterprise ERP o dedicated CMMS. CBM is developed through a balance between inspections and continuous monitoring. Data are analyzed in depth with CMMS. RCM is a standard practice based on maintenance software and is monitored and controlled.	Maintenance department defines budget and maintenance performance	Assessment of data from CMMS/ERP is develop by specialized team with formalized techniques. Maintenance performance are monitoring and evaluated. Contractors performance are periodically assessed.
DEFINED	Maintenance planning, spare parts management, budgeting and performance monitoring are made with Excel/Access. Maintenance activities in CMMS/ERP are modified after important failures. CBM based on continuous monitoring, data are analyzed with specialized tools. RCM occasional with Excel or Access.	Corrective maintenance procedures exist. Maintenance defines budget in accordance with top management	HSE policy managed by a specialized person. Cooperation between maintenance and production in order to define maintenance plans. Maintenance department formalized, standard activities defined. Occasional TPM, versatility of operators. Contracts choose by maintenance department after qualitative analysis.

	Maintenance Technological Maturity	Maintenance Management Maturity	Maintenance Organizational Maturity
MANAGE	Support tools on paper with regard maintenance planning, spare parts management, budgeting, performance monitoring. Maintenance activities loaded on CMMS/ERP only after installation. CBM based on continuous monitoring but there is no database in which register the result of monitoring, no RCM	Corrective maintenance is based on operators experience. Budgeting is not an activity of maintenance department	Assessment of data(maintenance, failure, equipment condition) made by analyst/team without a structured approach, HSE policy are a second activity of Maintenance manager. Maintenance and production interact only for corrective maintenance activities. Occasional TPM not implemented yet, outsourcing managed by maintenance manager
INITIAL	No supports used with regard maintenance planning, spare parts management, budgeting, performance monitoring. No modifications on maintenance plan, no RCM, CBM based only on periodic inspection	No managerial practices are developed	No analyst/team specialized in assess data, analysis only occasional, no one manage HSE policy, no empowerment practices. Relationship between maintenance and production not structured. Outsourcing activities not formalized.

Table 3.2 Reworking of Maturity Levels in TeSeM model

The table below shows how the questionnaire investigated the maintenance maturity, in terms of number of questions included for each PAs. All the questions are based on a set of closed answers: the respondent should select the answer describing the practice to which his / her own firm feels closer.

Index	Process Areas (PAs)	Questions
TMI	Monitoring, diagnostics and prognostics system	25
	Computerized maintenance management system	
	Reliability and maintenance engineering system	
OMI	Relationships with other enterprise functions	10
	Outsourcing (relationships with third parties)	
	Empowerment of maintenance personnel	
	Maintenance engineering structure	
MMI	Maintenance planning and budgeting	9
	Information sharing with third parties	
	Registration of maintenance work orders	

Table 3. 3 PAs investigated in TeSeM model

As we can see from the number of questions, the TeSeM maturity assessment goes more in depth in the technological area, while the organizational and managerial area can be extended with more insight on other practices.

3.4 The TUDelft Infrastructure Maturity Model

The Infrastructure Maturity Model (Volker et al., 2012) was developed under the request of Dutch Highway Transport Agency (Rijkwaterstraat). Also this model is based on the CMMI, and, in particular, it addresses its own PAs.

The PAs analyzed are then the followings:

- Information Management: It refers to the importance of having accurate and valid data on assets and processes, stored in adequate information systems, for measuring and comparing regional performances, agreements on service levels and budget allocation.
- Internal Coordination: In this axis, it is considered horizontal coordination within just one regional division for planning and execution of operational activities in one regional area at the lower maturity levels; on the other hand, horizontal coordination between the national agency and regional divisions in the process of

system planning and budget allocation is present as practice at the higher maturity level.

- External Coordination: It measures the extent of optimizing the system planning, operational planning and execution of works with third parties and the extent of communication with stakeholders. From the lowest to the highest maturity level we can see an increase of the coordination practices, until having a joint tactical system planning, operational planning and implementation.
- Market Approach: This approach considers the involvement of the knowledge that is available on the market. The knowledge of the market is used at the whole range of system planning, design and engineering, operational planning and execution of works. At the lowest maturity level, we see activity based contracts on a small scale. At the highest maturity level, contracts are performance based and cover networks instead of asset groups.
- Risk Management: It refers to the implementation of risk based methodologies for operation, maintenance and asset system management. Risk management performs well if there are predefined criteria, uniform methodologies for risk assessment, risk registers, asset system support. Good risk management on all levels is a prerequisite for effective budget allocation.
- Process and Roles: It measures the integration of the asset management system into the quality management system, job descriptions and human resources management. At the lowest maturity level, people are slightly aware of different asset management roles. At the highest level, asset management is fully integrated in the organizational structure.
- Culture and Leadership: It refers to the organizational processes which are required for implementing uniform asset management practices. Leadership and culture are necessary on all levels. High maturity means that people are aware of asset management, they have a positive attitude towards the changes, they are willing to learn new methodologies and they attend training

Based on a matrix developed by TUDelft within this model, in order to serve as a guide for understanding the different maturity levels, people from different hierarchical levels in the organization of the ten regional division of Rijkswaterstraat (RWS) were then interviewed with open questions.

The interviews were conducted by two interviewers, one from the university and one consultant, who spoke with two operational employees (such as data managers and

team leaders) and two employees at the tactical/managerial level (directors and strategic advisors).

Each interview was asked per dimension how the respondent would assess his/her own department on a scale from ad hoc to optimal. Later, the interview reports were sent to the interviewees for verification and the results were compared between different departments, between interviews and between different themes. Based on these information the maturity matrix was developed and finalized.

The same process was developed in 2011 and in 2012 to show the improvements reached by the different divisions. In the figure below we can see the results that emerged from the comparison between the two years.

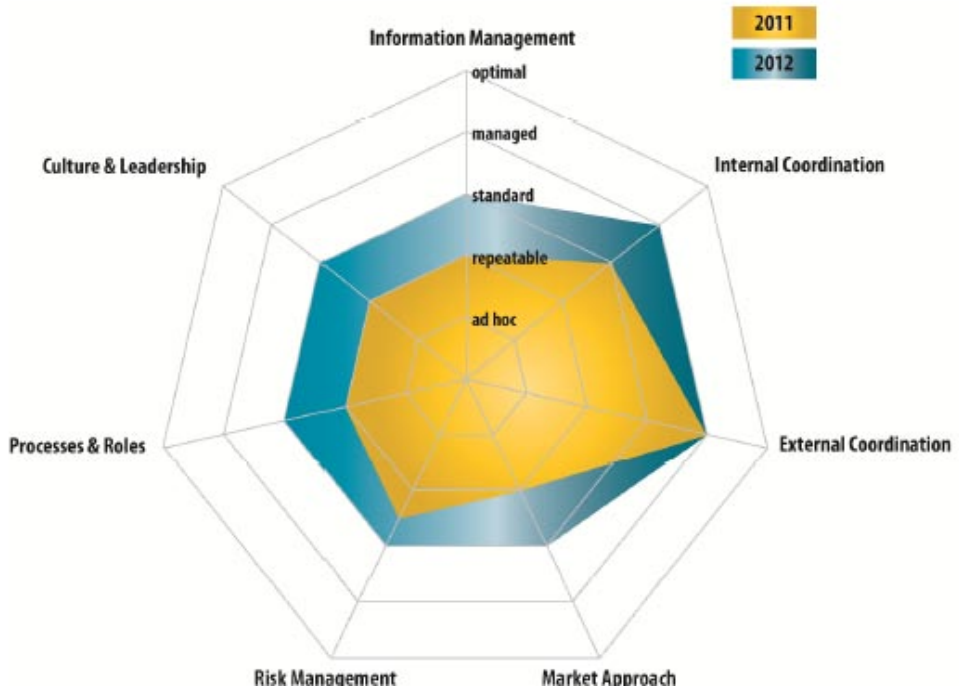

Fig.3.1 Results of the 2011 and 2012 measurement with the Infrastructure Management Maturity Matrix at Rijkswaterstraat (from Volker et al., 2012)

3.5 Considerations about the two models

The TeSeM maturity assessment model – and its questionnaire – were developed based on a number of characteristics, synthesized in the remainder.

- *As an "a priori" model*. This means that, for each answer in the questionnaire, it must be clear how to evaluate it in an unquestionable way, defining "a priori" a series of maturity levels. In this way, there will be no difference if maturity level is assigned by different interviewers/ evaluators.
- *For a survey-like assessment*: In order to define a rigorous measurement schema to be deployed in a survey, it was deemed necessary to evaluate maturity levels on the base of closed-answer questions. This introduces the other advantage of efficient data collection: the questionnaire is easier and quicker to fill in, and can be even used in phone interviews, or by less skilled people.
- *For a dynamic assessment*. The TeSeM research aims at focusing on the maintenance evolution. This means that, rather than providing a threshold to assign either a "good or bad" assessment, maturity levels must be defined in order to understand which could be the possible further improvements to a maintenance system.
- *For flexible adoption*. Since the TeSeM research aims at describing the state of the art of maintenance in different industrial sectors, the model is designed in order to be as much adaptable as possible at different needs and situations. This is eventually leading to offering generic descriptions and to assigning companies a maturity level without entering in implementation details, which could be different from one sector to another.

The result of the assessment allows to identify both a general maturity index and three specific indexes, so to evaluate which are the areas that need to be improved to increase the performance of the whole company. However, we can see that the assessment go more in depth on the technological aspect and omit important areas of the managerial and organizational indexes.

On the contrary, TU Delft matrix is specifically designed on Asset Management maturity, so it pays more attention, as a default, on organizational and managerial aspects; moreover, the human factors are really linked to the strategy and the

success of the company, and there are specific areas for the internal and external coordination.

Further on, by using open questions the interviewers may have the opportunity to make more considerations about the maturity profile of the organizations, modifying the questions in relation to the answers given by respondents and clarifying possible doubts during the interview. Moreover, double interviews (both at strategic and tactical levels) allow to collect considerations about the alignment and perceptions from different points of view.

In contrast, both data collection and analysis of the answers require more time and considerations, and it is linked to the experience of the interviewers. The analysis is particularly influenced by the knowledge of the sector and this was linked, in the TUDelft experience, to the fact that the matrix was developed only for the Road Authority. Henceforth, we cannot find the flexible propriety, strength of the TeSeM questionnaire.

At least, as a result both models provide a maturity score for each index but the reporting method differs: TUDelft model shows them in a radar charts, as the one reported in section **3.4**, while TeSeM with dashboards (Fig.3.2).

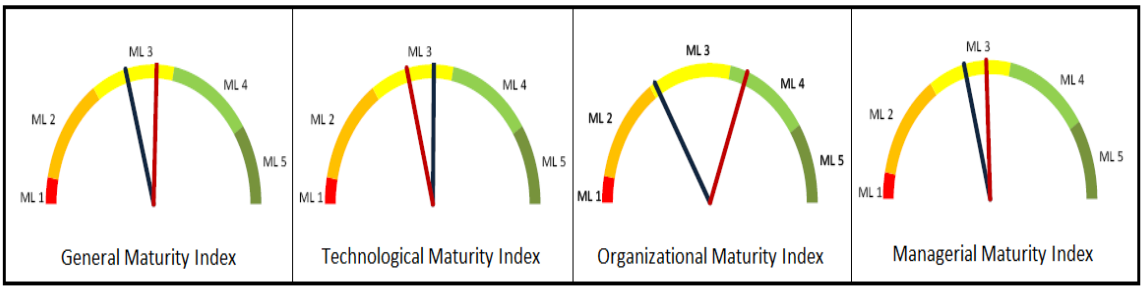

Fig.3.2 Example of dashboards in TeSeM model in which the red line represents the average maturity of the sector while the black line the maturity of the company (from report developed for individual company)

As we can see from the Fig.3.2, TeSeM model provides a numerical result also for the general maturity of the company through the dashboard of the GMI while looking the radar charts we can only have a graphical idea of the general maturity of the organization.

3.6 The Port et al. Maintenance Maturity Model

In technical and scientific literature we can find several maturity models about maintenance and asset management. We report Port et al. (2010) model for its holistic and integrated view.

According to these authors, the degree to which a company achieves maintenance excellence indicates its level of maturity. In particular, a maturity profile is a matrix that describes the organization's characteristic performance in each of the relevant elements for maintenance excellence: Fig.3. 3 presents an example of a profile that covers the spectrum of elements needed for maintenance excellence.

More specifically, for each element, the authors developed a matrix that describes organization characteristics.

- In the "leadership and people" element, an organization moves from reactive to proactive, and depends more heavily on its employees and shifts from a directed to a more autonomous workforce.
- The element of "Methods and processes" is about how firm manages maintenance. It includes the activities that people in the organization actually do. As processes become more effective, people become more productive. Poor methods and processes produce much of the waste effort typical of low-performing maintenance organizations.
- The element of "Systems and technology" represents the tools used by the people implementing the processes and methods organization choose. These are the enablers, and they get most of the attention in maintenance management. Generally, emphasizing technology without excellence in managing methods, processes and people will bring only limited success.
- The element of "materials and physical plant" expresses how well firm manages processes, methods and people. The management of all these aspects reflects on the reliability of the asset, on spare parts management but also on long term plans.

Concluding, it can be asserted that the Port et al. maturity model brings the following interesting contributions:

1. it proposes other indexes that can be considered in a maturity assessment;
2. it identifies, for each index, PAs and relative practices that can be linked to maturity levels.

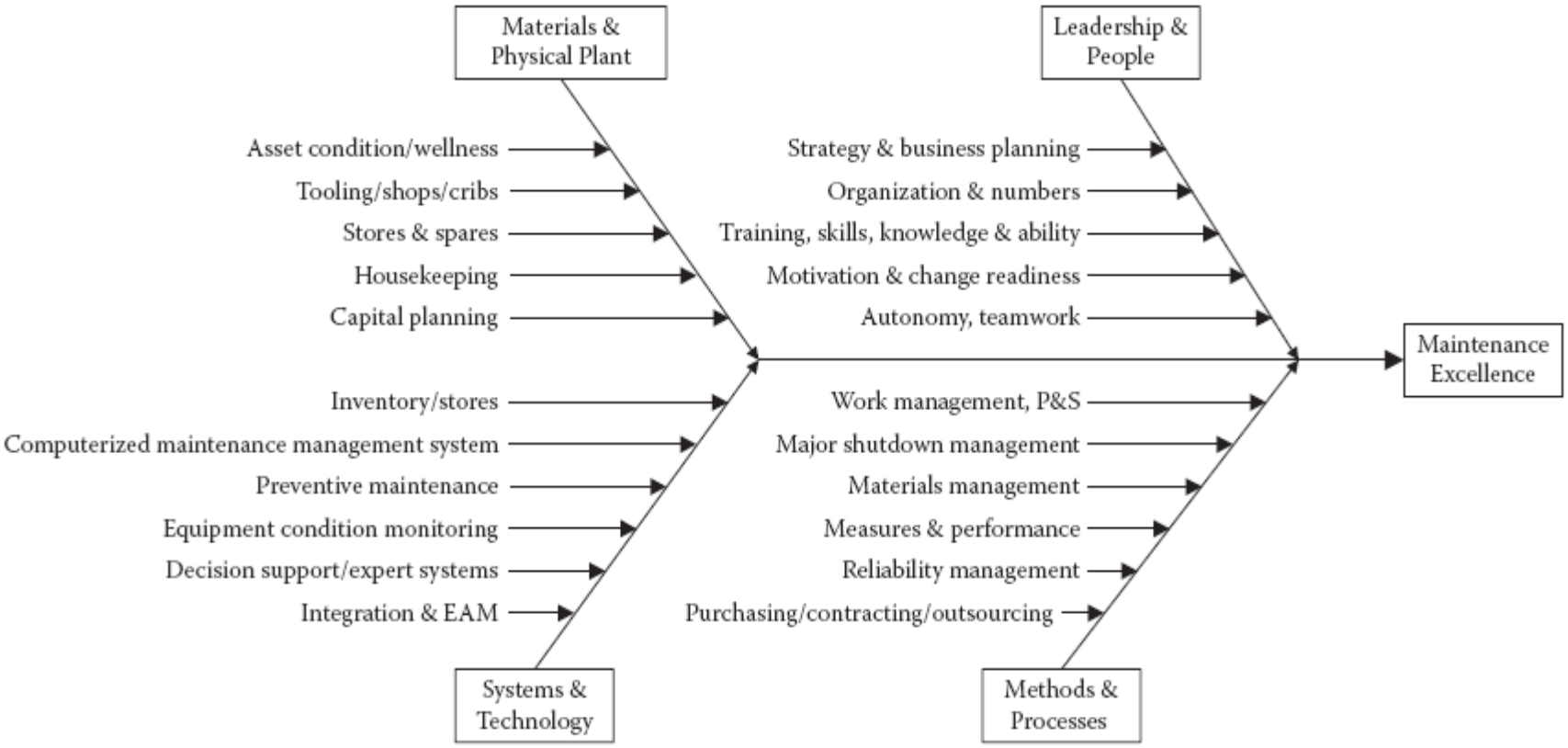

Fig.3. 3 Elements of maintenance excellence from Port et al., 2010

3.7 Concluding remarks

The Maturity Assessment model, proposed in this work (as presented in next chapter **4**), will integrate the main lessons learnt (and advantages) of the TeSeM and TUDelft model, including additional concerns as provided by the Port's model. This is the main outcome for what regards the methodological perspective.

For its development, the maturity assessment model will then require to be as flexible as possible in order to include practices of PAM, independently from the sectors of application. This is the main wish and intention inspiring the whole thesis work. The following actions should be justified in this direction, both for the model development – more generic than the TUDelft original one, more complete than the TeSeM original one –, and for the model use – in order to assess maturity in companies of different sectors, ranging from infrastructure to manufacturing –.

Chapter 4. The model for maturity assessment

In the model, proposed by this thesis work, the strengths of the two models presented in the previous Chapter 3 are combined.

The prime purpose of the research is to develop a **flexible model** that can be applied both in the manufacturing and infrastructure sectors. The development of the model will pass through the definition of a new maturity matrix (see Section **4.1**), from which a new questionnaire with closed questions will be derived as well (Section **4.2**).

We chose the closed questions methodology for the **a priori characteristic** that allows different advantages: (i) to force a respondent to answer in a standard way (otherwise we might have different answers, possibly related to the sector of the company), (ii) to simplify the analysis of the answers in a general model; (iii) to enable cross comparison between the cases under analysis.

The questionnaire should be filled in by the asset manager of the organization, or a close equivalent if this position is not present.

Even if we choose a specific respondent, the asset manager, we must not forget that asset management is also about process. Instead of a hierarchical organization where decisions and budgets follow the chain of command into functional silos, physical asset management is a single process that links asset owners, asset managers, and asset service providers in a manner that allows all spending decisions to be aligned with corporate objectives supported by asset data (Brown and Humphrey, 2005). Henceforth, in the development of the maturity model we must not only consider the asset plan aspects, typical of asset manager organizational duties, but also the links with the other figures, such as information flow and culture aspects, performance assessment, life cycle and risk based management. Ideas to this regard, in order to develop the model – i.e. on typical PAM practices –, can be generated and sourced from literature accordingly to the review already provided in the previous Chapter 2.

4.1 The Maturity Matrix

In accordance to what already discussed and learnt in Chapter 3, the first step regards the choice of how to develop the maturity matrix, indexes and process areas of each index.

As said before, the three indexes used in the TeSeM model fit well with the analysis of a maintenance service but they omit important aspects that have to be considered in the extended field of PAM Assessment. On the contrary, the seven indexes identified in the TUDelft matrix are too linked to the field of application of the model: for example, the internal coordination – within this matrix – regards the divisional structure of the Road Authority and hence the need to structure a shared way to communicate between different departments.

Another consideration concerns the number of indexes, which become the columns of the matrix, and their relationship with Process Areas (PAs) for which PAM practices are investigated. We select the closed questions assessment, so for each PA we have to find a set of questions that can explain the maturity of that PA, in relation to different levels of PAM practices (basic, good, best … practices). Each PA is then associated to an index. This leads to the need to solve a tradeoff between the depth of the analysis and the number of questions included in the questionnaire for maturity assessment. With a high number of columns in the matrix/indexes, the assessment can cover more aspects/PAs of PAM, but we need to have a lot of questions: this might discourage the respondents. On the contrary, we have to find enough columns/indexes through which we can do an exhaustive work of analysis through relevant PAs.

We identify four important maturity indexes/columns of the matrix, used to calculate the maturity in different Process Areas.

- **Management Decisions**. It refers to the main decisions that the asset manager has to consider in managing the asset management of the firm, taking into account the asset life cycle management, risk management and maintenance management.
- **Information Management**. It refers to the aspects of information management related to ICT tools/systems, monitoring and prognostics methods, registration of data and performance management.

- **Organization and Culture**. Herein, we go in depth in the organizational issues. The asset management team, culture, communication and training are topics taken into account under this index.
- **External Coordination.** This index concerns the relationships with third parties such as stakeholders, regarding the ability to understand and follow their requirements, and contractors, regarding the shared information and plans.

In Table 4.1 the process areas related to each index are summarized.

Index	Process Areas
Management Decisions	Asset Life Cycle Management
	Risk Asset Management
	Maintenance Management
Information Management	Information systems
	Asset Performance Management
Oganizational & Culture	Asset Management Function and Group
	Asset Management Culture
	Communication
	Training
External Coordination	Regulators
	Society
	Contractors

Table 4.1 Process area of the new model

Concerning the maturity levels, we decide to use the five levels defined along the continuum of the CMMI. The levels will be associate to a correspondent maturity score.

- **Initial** (also chaotic, ad hoc, individual heroics): the starting point for use of a new or undocumented repeat process
- **Managed** the process is at least documented sufficiently such that repeating the same steps may be attempted
- **Defined**: the process is defined/confirmed as a standard business process, and decomposed to tactical and operational levels
- **Quantitatively Managed**: the process is quantitatively managed in accordance with agreed – upon metrics

- **Optimizing**: process management includes deliberate process optimization and improvement.

4.2 The questionnaire

Here after we present how we decide to develop the questionnaire, explaining the choice of the questions and the calculation of the indexes. In particular, the evaluation of the answers has assigned a maturity score: this is related to the definition given in the matrix and related maturity levels (i.e. hence it may be, in case of maximum range completely used, from 1 to 5).

The questionnaire is divided in five parts (A – E). The first one is an introduction to the survey, the others one are linked to the columns/indexes of the matrix.

A) General information

Here we ask to the asset manger to give some information about the company, such as place of assets, sector, and concept of PAM.

B) Management Decisions Index (MDI)

In this column of our matrix, we consider three aspects/PAs of PAM:

- Asset life cycle cost management
- Asset risk management
- Asset maintenance management

For each of them, we calculate a maturity score, starting from the score achieved in each answer. The maturity of the Management Decisions Index will be the average of the three scores.

B.I) Asset life cycle cost management

The main objective of the LCC analysis is to quantify the total cost of ownership of a product/asset throughout its full life cycle, which includes research and development, construction, operation and maintenance, and disposal. The predicted LCC is a useful information for decision making in purchasing a product, in optimizing design, in scheduling maintenance, or in planning revamping (Kawauchi and Rausand, 1999).

The results of costs analysis in asset management decision making can be used for different purposes. The first question wants to inquire these uses (in the remainder, the questions are put in evidence by formatting in italics).

B.I.1) The result of costs analysis in asset management decision making, in your organization, are used for:

- □ *Acquisition and development of projects*
- □ *Support process system design.*
- □ *Identify better investment options (investment, repair,..)*
- □ *Identify redundancy – equipment and systems.*
- □ *Plan Maintenance programs.*

As we said in the literature review, a complete life cycle cost analysis has to consider operation costs (OPEX) and capital costs (CAPEX). The following question wants to investigate the completeness of costs analysis.

B.I.2) Which types of assets' costs does your organization consider to support decision making for PAM?

When assets are acquired from suppliers

- □ *Purchase price*
- □ *Installation costs*
- □ *Operational costs*
- □ *Disposal Costs*
- □ *Others:_____*

When assets are designed by internal functions of the organization

- □ *R&D*
- □ *Design Costs*
- □ *Installation Costs*
- □ *Operational Costs*
- □ *Disposal Costs*
- □ *Others:_____*

Which kind of operational costs does your organization consider?

- □ *Energy costs*
- □ *Planned maintenance*
- □ *Corrective maintenance*
- □ *Security*
- □ *Environmental (carbon footprint, treatment of waste,…)*
- □ *Lack of production*
- □ *Others:_____*

Questions B.I.1 and B.I.2 are not linked to a direct maturity score but they are used both as introduction to the argument for the other questions and as an help in the assessment in a qualitative way. From B.I.3 the quantitative questions are developed.

First of all, we want to take in consideration that the cost analysis is really effective only if people understand the importance of it.

B.I.3) The importance of cost analysis, in PAM decisions, is understood by [multiple choice possible]:

Answer	***Maturity Score***
Only the asset manager	*1*
Only the asset management team	*2*
Part of the people who act on the operational level	*3*
Part of the people who act on the tactical/planning level	*3*
All the people who act on the operational level	*4*
All the people who act on a tactical / planning level	*4*

The efficiency of the cost analysis depends also by the way through which the company employs it.

B.I.4) Is cost analysis, relating to PAM decisions, structured in your organization?

Answer	***Maturity score***
No	*1*
Yes, only occasionally, just a cost analysis without making a LCC analysis	*2*
Yes, only occasionally, making LCC analysis for some PAM decision makings	*3*
Yes, a structured methodology for LCC analysis exists, which is regularly applied for the most important PAM decision makings	*4*

Other:_____

To use a LCC analysis as support for decision-making, we must consider not only cost but also data related to effectiveness. The effectiveness may comprise many system characteristics, like production capacity, product quality etc., and also system performance characteristics, like system availability, the safety integrity level of shutdown systems, etc. Regulations, codes and standards, and project specifications may specify the system effectiveness in many cases.

B.I.5) In your organization, during LCC analysis related to PAM, do you collect data about:

- □ *Failures & reliability of asset*
- □ *Capacity of assets*
- □ *Quality of the process (product or service delivered)*
- □ *Safety*
- □ *Environmental impact*
- □ *Other:_____*

All the information needs to be integrated in order to manage them in an effective way in the information system.

B.I.6) Are these data from question B.I.5 managed within an integrated information system?

Answers	***Maturity Score***
No, the information system providing the data is not integrated; data / information are quite dispersed, manual integration is strongly needed	*1*
Yes, the information system providing the data is partly integrated; data / information are dispersed, manual integration is present but the effort is reduced	*2*
Yes, an integrated information system, providing data / information as a platform, is already present; people work more at the level of decision making (i.e. transforming data / information available to knowledge enabling decisions).	*4*

During life cycle costs analysis a lot of information is required. Data need to be updated and without uncertainty. To this end, it is important that organizations clarify who has the organizational duty to fill the data in the information systems.

B.I.7) Who has the organizational duty to fill the data / information, relating to PAM decision making, in the information system?

Answers	***Maturity Score***
Only the asset manager	*1*
There are dedicated persons (indicate the functional area of the operators, more than one functional area is applicable: _____)	*2*
The asset management team	*3*
All the operators can fill the databases (indicate the functional area of the operators, more than one functional area is applicable:_____)	*4*
All the operators can fill the databases (indicate the functional area of the operators, more than one functional area is applicable:_____) *and it is checked for consistency.*	*5*

In assigning the scores for the previous question we assume that if more people can fill and update data, the information flow should be faster and more effective. Someone can argue that if more people can access to databases the probability of mistakes increases. For this reason the best solution includes also a check for the consistency.

Another important aspect regarding LCC is the uncertainty that we have around data. In fact, almost all of them come from estimates and in order to have an effective LCC analysis is fundamental that these estimates are accurate and constantly updated.

B.I.8) Where do estimates, used in PAM cost analysis, come from? [Multiple choice]

Answers	***Maturity Score***
Experience of managers/operators/project team	*1*
Suppliers	*2*
Analysis of historical data based on the simple average of data.	*2*
Analysis of historical data based on more sophisticated tools/based on previous projects	*3*
Parametric techniques based on statistical- distribution analysis of historic databases.	*4*
Quantitative models developed in order to take into account the random/stochastic nature of events and relying on the use of specialized statistical techniques to "simulate" future decisions.	*5*

B.I.9) Are these estimates periodically updated?

Answers	***Maturity Score***
No	*1*
After important events (overhaul, incidents, new machine installation)	*2*
Periodically updated (namely how often:_____)	*3*

LCC analysis includes a lot of activities, some of them very often are carried out from third parties. Hence, sharing information becomes fundamental.

B.I.10) Sharing information with third parties. Contractors: [multiple choice]

Answers	***Maturity Score***
Have to deliver information and there is a person/a team with the organizational duty of update PAM information systems	*2*
Can access to PAM information systems	*3*
Can update PAM information systems	*4*
Can insert[1] data in PAM information systems	*5*

A **summarizing table**, reporting all the possible answers given in this part of the questionnaire, is presented in Table 4.2.

		Life cycle cost management				
		Maturity Score				
	B.I	1	2	3	4	5
Questions	3	answer.1	answer.2	answer.3/4	answer.5/6	
	4	answer.1	answer.2	answer.3	answer.4	
	6	answer.1	answer.2		answer.3	
	7	answer.1	answer.2	answer.3	answer.4	answer.5
	8	answer.1/2	answer.3	answer.3	answer.4	answer.5
	9	answer.1	answer.2	answer.3		
	10		answer.1	answer.2	answer.3	answer.4

Table 4.2 Summarizing table - LCMi

The formula of LCMi (Life Cycle Management index), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

[1] Insert means that contractors can add new types of information, such as new performance indicators, new information about assets.

$$LCMi = \frac{\sum_{q=3}^{10} B.I_{iq}}{7}$$

Where:

- q is the index of the question
- B.I.$_{iq}$ is the score obtained by the firm *i* in the question indexed as q.

Observation: As reported, not every question has five possible answers (five maturity levels). In the next table, it is represented the score that can be reached by a firm that answers at these questions with the same score and where it is not possible with the lower one as close as possible.

		Life cycle cost management				
		Maturity Score				
	B.I	**1**	**2**	**3**	**4**	**5**
Questions	**3**	1	2	3	4	4
	2	1	2	3	4	4
	6	1	2	2	4	4
	7	1	2	3	4	5
	8	1	2	3	4	5
	9	1	2	3	3	3
	10	1	2	3	4	5
average		1	2	2,875	3,875	4,375

Table 4.3 Simulation Score – LCMi

B.II) Risk asset management

As we said in the literature review, the purpose of Risk Asset Management is to understand the cause, the effect and the likelihood of adverse events which may occur while an organization is managed. Indeed, PAM is often viewed as an integrated approach to balance costs, performance and risks during all asset life cycle, hence risk asset management became fundamental.

There are different types of risks to consider in the organization.

B.II.1) What types of risks does your organization consider?

- □ *Operational risks caused by:*
  - □ *Functional failure*
  - □ *Incidental damage*
  - □ *Human Factors*
  - □ *Others:_____*
- □ *Natural environmental risks (storms, floods,...)*
- □ *Financial risks*
- □ *Stakeholders risks (such as failure to meet regulatory performance requirements or reputation damage)*
- □ *Suppliers risks*
- □ *Others:_____*

Risk management analysis can be adopted in order to support different decisions, or to simply provide communication through the interested parties.

B.II.2) The results of risk management analysis are used to:

- □ *Provide a common communication tool.*
- □ *Support process system design.*
- □ *Identify redundancy – equipment and systems.*
- □ *Plan Maintenance programs.*
- □ *Identify spare parts requirements.*
- □ *Target maintenance budgets.*
- □ *Identify training requirements.*
- □ *Identify skill based risk.*
- □ *Quantify the maintenance commitment KSF's, KPI's.*
- □ *Provide a basis for system modeling.*
- □ *Indentify the better options (investment, repair,…)*
- □ *Other:_____*

Also in this case, these first questions are not used in the assessment directly but they are used for qualitative considerations. Instead, next questions have maturity

scores: they refer to the way the risk management process is carried on, to its understanding in the organization, as well as to its responsibility.

B.II.3) Is there a risk asset management process in your organization?

Answers	***Maturity Score***
No	*1*
Yes, but it is not standardized	*2*
Yes, and it is standardized (as an enterprise standard)	*4*
*Yes, and it is standardized (as an enterprise standard, considering also certifications / norms from third parties / institutions)**	*5*

** specify if there are certifications about risk management process (such as ISO/IEC guide 73/2002)*_____

B.II.4) The importance of risk analysis is understood by

Answer	***Maturity score***
Only the asset / risk manager	*1*
Only the asset management team	*2*
Part of the people who act on the operational level	*3*
Part of the people who act on the tactical / planning level	*3*
All the people who act on the operational level	*4*
All the people who act on the tactical / planning level	*4*

B.II.5) Who is responsible for Risk analysis?

Answer	***Maturity score***
There is none responsible for it	*1*
Asset manager	*2*
Risk manager	*3*
There is a function responsible for it	*4*

Regarding the assessment of this question, we have to develop some considerations. In particular, we assume that it is preferable to have a risk manager than a general asset manager because it means that there is a dedicated figure for risk asset management. Moreover if there is a function we can assume that there are dedicated persons that try to achieve the continuous improvement. In fact as a Risk Management Standards (AIRMC, 2002) says some of the roles of the Risk management function are:

- designing and reviewing processes for risk management;
- coordinating the various functional activities which advise on risk management issues within the organization;
- developing risk response processes, including contingency and business continuity programs;
- preparing reports on risk for the board and the stakeholders;

and all these duties are part continuous improvement concept.

There are a lot of methods that can be used to assess risks, from qualitative to quantitative approaches. In general quantitative analyses are preferred because they are considered more objective. However in some cases it is impossible to quantify in a correct way a risk, so in these situations qualitative analysis can be more useful.

B.II.6) Risk assessment is developed through

Answers	***Maturity Score***
Only qualitative analysis	*1*
Only quantitative analysis	*3*
There is a balance between qualitative and quantitative analysis	*5*

One of the most used output from risk management analysis is the risk matrix. A risk matrix is a simple graphical tool that combines:

- the chance for an occurrence of an event (Probability) (usually an estimate)
- the Consequence if the event occurred (usually an estimate)
- put the twos together as: Risk = Probability * Consequence

Risk matrix is an important tool to categorized risks, prioritize actions, define the acceptable level of risk.

B.II.7) Do you have a risk matrix or other similar tool to express, in a visual way, the risk of different entities under concern?

□ *No*
□ *Yes**

**which tool?* _____

Observation: For the evaluation of yes/no questions, such as question B.II.7, we decide to consider the maturity score only in case of "no" as answer (ML = 1). In other cases, considering another value can falsify the mean. For example, for a firm with high maturity, adding 2 as score in the formula of ARM_i (Asset Risk Management index)can considerably decrease the result.

In the LCC section we made some consideration about the need of sharing information and knowledge and the need of updated data. Same considerations can be done regarding risk management.

B.II.8) Who has the organizational duty to update the risk matrix/risk database?

Answers	***Maturity Score***
Only the manager responsible for it (indicate the functional area responsible for it:_____)	*1*
There is a dedicated team (indicate the name of the unit / function in the organization:_____)	*3*
All the operators can access to data (indicate the functional area of the operators, more than one functional area is applicable:_____)	*4*
All the operators can access to data (indicate the functional area of the operators, more than one functional area is applicable:_____) and there is a check for the consistency	*5*

B.II.9) Are risk data periodically updated?

Answers	***Maturity Score***
No	*1*
They are updated after important events (overhaul, incidents, new machine installation)	*2*
They are periodically updated (indicate how often:_____)	*3*

Also in this case it is important that third parties can access to risks data.

B.II.10) Share information with third parties. Contractors:

Answers	***Maturity Score***
Have to deliver information and there is a person/a team with the organizational duty of update risks database	*2*
Can access to risks database	*3*
Can update risks database	*4*
Can insert data in risks database	*5*

As in previous section, a **summarizing table** reporting all the possible answers given in this part of the questionnaire is presented in Table 4. 4

		Asset Risk Management				
		Maturity Score				
	B.II	1	2	3	4	5
Questions	3	answer.1	answer.2	answer.3	answer.4	answer.5
	4	answer.1	answer.2/3	answer.4/5	answer. 6/7	
	5	answer.1	answer.2	answer.3	answer.4	answer.5
	6	answer.1		answer.2		answer.3
	7	no	yes			
	8	answer.1		answer.2	answer.3	answer.4
	9	answer.1	answer.2	answer.3		
	10		answer.1	answer.2	answer.3	ansewer.4

Table 4. 4 Summarizing table - ARMi

The formula of ARMi (Asset Risk Management index), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$ARMi = \frac{\sum_{q=3}^{10} B.II._{iq}}{8}$$

where:

- q is the index of the question
- $B.II._{iq}$ is the score obtained by the firm *i* in the question indexed as q.

B.III) Maintenance management

Concerning maintenance management decisions a lot of questions were developed in the TeSeM questionnaire. However maintenance is one of the most important aspects of asset management, so we decide to include questions, doing a little summary about the principal practices.

We can classify maintenance management decisions in three categories: corrective maintenance, preventive maintenance, proactive maintenance.

Corrective Maintenance: It consists of the actions taken to restore a failed system to operational status; this usually involves replacing or repairing the component that is responsible for the failure of the overall system. Corrective maintenance is performed at unpredictable intervals, with the objective to restore the system to satisfactory operation within the shortest possible time.

Observation: Corrective maintenance is an activity of the operational level under the responsibility of the asset service provider. For this reason we decide to omit questions about this argument. Different are the considerations about preventive and proactive maintenance that are included in maintenance planning activities and so are also at the tactical / planning level.

Preventive Maintenance. Unlike corrective maintenance, this is the practice of replacing components or subsystems before they fail, in order to promote continuous system operation, reducing failure or degradation probability. In this way, in fact, downtimes are briefer and production losses are fewer. This can be done:

1) At fixed time or utilization intervals, without considering the equipment condition (Cyclic preventive maintenance);
2) Monitoring the condition of the equipment, defining if it has to be maintained or not (Condition-Based Maintenance).
3) Predicting, thanks to mathematical models of the evolution of equipment behavior, its Remaining Useful Life (RUL) and planning the maintenance actions according to the expected moment in which it should fail (Predictive maintenance).

To choose between different options of preventive maintenance (or, at least, to decide that corrective is better), designing the maintenance plan is needed.

B.III.1) Design of maintenance plan[2]. How do you define your preventive maintenance plan? [single choice]

Answers	***Maturity Score***
According to operators' experience	*2*
According to operators' experience and vendor recommendations	*3*
Using tools of quantitative analysis to define / redefine the best time to do preventive maintenance	*4*
Evaluating the results obtained with the last plan and using quantitative tools to redefine maintenance periods/to make continuous improvements	*5*

Proactive Maintenance. This maintenance policy comes from Total Productive Maintenance (TPM) philosophy; its objective is to improve asset reliability and maintainability, thanks to continuous little improvements with the help of maintainers and production personnel.

TPM is typically considered a pillar representing a set of good maintenance practices.

B.III.2) TPM Is Total Productive Maintenance (TPM) implemented in your company?[3] [single choice]

Answers	***Maturity Score***
I do not know what TPM is	*1*
No	*1*
Occasionally, we have tried in the past but we did not achieve it	*2*
Occasionally, we use TPM practices but not in a constant and systematic way It is a standard practice in the company	*3*
It is a standard practice in the company	*5*

[2] From TeSeM
[3] From TeSeM

Another important approach/pillar to maximize maintenance performances is Reliability Center Maintenance (RCM). RCM is a logical, structured framework for determining the optimum mix of applicable and effective maintenance activities needed to sustain the operational reliability of systems and equipment while ensuring their safe and economical operation and support (Criscimagna, 2002).

B.III.3) RCM. Do you perform Reliability Centered Maintenance (RCM) in your company? [single choice][4]

Answers	***Maturity Score***
I do not know what RCM is	*1*
No	*1*
Yes, but only in some department	*3*
Yes, in the whole organization	*5*

B.III.3.1) If yes, how does RCM is performed?

Answers	***Maturity Score***
Occasionally, recording results on (ex. Microsoft Excel)	*3*
Occasionally, recording results on an electronic database	*3*
It is a standard practice based on software tools for maintenance engineering	*4*
RCM processes are performed, monitored and controlled (the quality of the process is verified)	*4*
RCM processes are constantly improved according to the feedback coming from the process quality measurements	*5*

[4] Adapted from TeSeM

Table 4.5 reports the summary of the questions on maintenance management area.

		Maintenance Management				
		Maturity Score				
	B.III	1	2	3	4	5
Questions	1		answer.1	answer.2	answer.3	answer.4
	2	answer.1/2	answer.3	answer.4		answer.5
	3	answer.1/2		answer.3		anwer.4
	4			answer.1/2	answer.4	answer.5

Table 4.5 Summarizing table - MMi

The formula of MMi (Maintenance Management index), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$MMi = \frac{\sum_{q=1}^{4} B.III._{iq}}{4}$$

where:

- q is the index of the question
- $B.III._{iq}$ is the score obtained by the firm *i* in the question indexed as q.

Finally, the MDI (Management Decisions index) for the generic firm i can be calculated as:

$$MDIi = \frac{LCMi + ARMi + MMi}{3}$$

As we used the real numbers in the MDIi formula, we do not need to calculate in advance the LCMi, ARMi and MMi and we can do the average of the all answers. However, calculating the three indexes helps to understand better which are the critical areas and to prioritize improvement actions: hence, a diagnostic purpose, more than a computational reason, recommends the separation of the MDIi in its component indexes.

Consideration about the Management Decisions Index

This index, and the correspondent column of our maturity matrix, is probably the most important one, because it includes a lot of aspects that can be linked to other columns. For example:

- the need of integrated and update database for LCC and risk management can be linked to the information flow column;
- the need to share information with contractors includes aspects of external coordination column;
- the need to share knowledge between operators includes aspects related to the organizational & culture column.

For these reasons we can expect that organization cannot reach a high global maturity score without having a high decision process score. On the other side, a company cannot have a high decision process score without having high score in the other indexes, because it depends from information, knowledge and relationships with third parties. Hence, it is clear also from this consideration the holistic character of PAM.

C) Information Management Index (IMI)

In this section we explain how the maturity index is calculated for what concern managing information and performance assessment.

In the TeSeM model there are a lot of questions about this layer, most of them are specific to the maintenance issues. In this part we have tried to adapt the existent questionnaire to Asset Management.

Information system can be then interpreted as doing the activities, required in the PAM scope, with the support of more or less standard information tools.

C.I) Information System

C.I.1) Use of information systems. Which support do you use for the following management activities[5]?

	Not performed	In paper	Excel/ Excel + Access	Function of company's ERP[6]/EAM[7]	CMMS[8]	other	Not applicable
Budgeting and planning of maintenance activities	1	2	3	4	4		
Third companies/ outsourcing management	1	2	3	4	4		
Management of technical drawing and documents	1	2	3	4	4		
Reliability and maintainability performance assessment	1	2	3	4	4		
KPI monitoring and reporting	1	2	3	4	4		
Risk management	1	2	3	4	4		
Life Cycle cost management	1	2	3	4	4		

In the table above, we can find all the aspects of asset life cycle management from the investment and design phase, with risk management, life cycle cost and design, to the utilization phase, with maintenance management and performance assessment. We ask the supporting tools to these activities along the life cycle.

Some authors argue about the higher score given to ERP / EAM / CMMS than Microsoft Excel tools because they think that it is better to have a simple tool, such as Excel, instead than sophisticated ones that employees cannot use well. In our analysis we assume that with tools such as ERP/CMMS a better integration can be reached and an integrated information flow is the basis for a high maturity.

Very often a company spends efforts in collecting data but data without analysis done by competent persons are completely useless.

[5] Adapted from TeSeM
[6] ERP (Enterprise Resource Planning)
[7] EAM (Enterprise Asset Management)
[8] CMMS (Computerized Maintenance Management System)

C.I.2) Is there a competent analyst or an analysis team for the analysis of data concerning asset management:[9] [single choice]

Answer	***Maturity Score***
No	*1*
Yes, only part of data	*2*
Yes, only for economical data	*3*
Yes, only for technical data	*3*
Yes, able to analyze technical and economical data	*5*

Another aspect to highlight is that data are not static but change during the time. Hence it is necessary to have databases and system updated.

C.I.3) Review of plans and procedure in the CMMS / ERP / EAM.
How often the maintenance plans or procedures have been modified after CMMS / ERP / EAM implementation (excluding updates)? [single choice][10]

Answer	***Maturity Score***
Never	*1*
Plan and procedures are loaded into the CMMS / ERP /EAM only after plant installation	*2*
Plan and procedures are loaded into the CMMS / ERP after plant installation and after the occurrence of major events (overhaul, incidents, incidents, new machine installation)	*3*
Changes in plans and procedures into the CMMS / ERP are results of regular improvements leaded by maintenance management	*5*

[9] From TeSeM
[10] From TeSeM

The following questions regard then the data life cycle, an important topic for PAM, as discussed in the literature review.

C.I.4) Data on assets condition are collected

Answer	***Maturity Score***
Without systematic procedures	*1*
Only after important events (overhaul, incidents, new machine installation)	*2*
After Periodic inspections	*3*
Through continuous monitoring	*5*

C.I.5) Where does your company storage data about asset condition?

Answer	***Maturity Score***
Company does not have a structured database	*1*
There are different database not shared by separate functions	*2*
There is a shared database but it is difficult to find data in it	*3*
There is an integrated and easily used database	*5*

C.I.6) How are analysis about asset condition developed?

Answer	***Maturity Score***
Analysis about data are poor / almost non existent	*1*
Data are analyzed occasionally without a standard way	*2*
Data are used in TPM/RCM/statistical analysis	*5*

Not only data but also tools are dynamic one. New tools are developed in order to help managers and operators in managing a huge quantity of information and extending supported functionality.

C.I.7) Do you use tools such as PDAs (personal data assistant), smart-phone,.. to support asset management activities[11]?

- □ *No*
- □ *Sometimes*
- □ *Yes*

The Table 4.6 reports all the possible answers given in this part of the questionnaire.

		Information System				
		Maturity Score				
	C.I	1	2	3	4	5
Questions	1	m.answer.1	m.answer.2	m.answer.3	m.answer.4	
	2	answer.1	answer.2	answer.3/4		answer.5
	3	answer.1	answer.2	answer.3		answer.4
	4	answer.1	answer.2	answer.3		answer.4
	5	answer.1	answer.2	answer.3		answer.4
	6	answer.1	answer.2			answer.3

Table 4.6 Summarizing table IFSi

One of the possible formulas of IFSi (Information System index), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$IFSi = \frac{\sum_{q=1}^{6} C.I_{iq}}{6}$$

where:

- q is the index of the question
- $C.I_{iq}$ is the score obtained by the firm *i* in the question indexed q.

[11] Adapted from TeSeM

However, we assume that the question C.I.5 is one of the most important in this section because it reflects the real situation of the company about information system: for example, a company can in fact have sophisticated information tools but they are not well structured and it is time consuming to find data in them, because of a scarce integration. Hence, we decide to assign a higher weight to this question. The adapted formula of IFSi became:

$$IFSi = \frac{C.I.1_i + C.I.2_i + C.I.3_i + 4 + C.I.6_i}{5} \; x\; 0{,}4 \; + C.I.5_i \; x\; 0{,}6$$

C.II) Asset Performance Management

The performance monitoring represents the upstream information flows discussed in the paragraph **2.4.2** which provides feedback on effectiveness of the implementation of asset management strategies.

There are a lot of KPIs related to physical asset management that can be monitored by organizations.

C.II.1) What KPIs related to physical asset management are used in your organization? [multiple choice]

- □ *Reliability*
- □ *Availability*
- □ *Maintainability*
- □ *Safety*
- □ *Security*
- □ *Health*
- □ *Environmental*
- □ *Quality of the business results (quality of products / service…)*
- □ *Economics*
- □ *Politics (relationship with stakeholders as regulators..)*
- □ *Customer Satisfaction*
- □ *Employees Satisfaction*
- □ *Training*
- □ *Others [indicate them]:_____*

As we said in the literature review, if the importance of performance measurement system is not understood by the whole organization, and monitored with adequate frequency, the benefits of managing it will not be totally achieved.

C.II.2) The importance of performance measurement is understood by:

	Strongly Disagree	***Disagree***	***Agree***	***Strongly Agree***
Board of Directors				
Managers				
Operators				

C.II.3) Is there a responsible of KPIs monitoring?

- □ *Nobody*
- □ *Every managers*
- □ *The quality assurance department*
- □ *Different department (indicate them:_____)*

C.II.4) How often do you usually monitor KPIs in your organization?

Answers	***Maturity score***
They are never monitored	*1*
They are periodically monitored without a standard frequency	*2*
A standard frequency is defined	*3*
They are continuously monitored	*5*

For each KPI, the company has to identify a target and verify discrepancies with was actually attained. Targets should be challenging but achievable and should reflect market/customers requirements.

C.II.5) How often are the target of KPIs set in your organization?

Answers	***Maturity score***
Only once	*1*
After important events (overhaul, incidents, new machine installation,..)	*2*
Periodically (indicate how often:_____)	*3*
Periodically (indicate how often:_____) but they are revised during this period	*4*

C.II.6) Do standard procedures exist to deal with discrepancies between the actual performances and the target performance?

Answers	***Maturity score***
No, discrepancies analysis is not developed	*1*
No, discrepancies analysis is occasionally developed without standard practices	*2*
Yes, there are standard practices	*3/4**

in this case the maturity is also influenced by the next question:*

C.II.7) If discrepancies analysis is developed, does it affect decisions?

	NO	***Sometimes***	***Yes***
Of board directors			
Of Manager			
Of operators			

In particular, if discrepancies analysis affects decisions at the all levels of the organization, the maturity score of C.II.6 will be 4, in other cases 3.

Here after the summarizing table about the asset performance assessment section in shown (Table 4.7)

		Asset Performance Management				
		Maturity Score				
	C.II	1	2	3	4	5
Questions	4	answer.1	answer.2	answer.3		answer.4
	5	answer.1	answer.2	answer.3	answer.4	
	6	answer.1	answer.2	answer.3		

Table 4.7 Summarizing table - APMi

The formula of the APM_i (Asset performance management), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$APMi = \frac{C.II.4_i + C.II.5_i + C.II.6_i}{3}$$

where:

- q is the index of the question
- $C.II._{iq}$ is the score obtained by the firm *i* in the question indexed as q

Hence the formula of the Information Management Index is:

$$IFMi = \frac{IFSi + APMi}{2}$$

D) Organization & Culture Index (OCI)

D.I) Organization

One of the important aspects to consider, analyzing PAM maturity, is to understand if asset management is recognized in the organization as a function. As it is said in the literature review, the purpose of the Asset Management Function is to provide resources and expertise to support the acquisition, in-service support and disposal of the physical assets required by the organization. An asset management function will be needed at company level, providing inputs to asset planning, taking a role in major

acquisitions and developments and providing the systems and facilities needed to support assets throughout their life (Hastings, 2010).

D.I.1) At which level is the asset management function in place? [multiple choice]

□ *Operational*
□ *Tactical*
□ *Strategic*

If the asset management function is only at one level we assign "1" as maturity score; on the contrary, if the PAM function is at the three levels the maturity score will be "5". In the intermediate situation (at two levels) the maturity score will be "3".

According to Hasting, we assume that an effective asset management function need to identify a specific and multidisciplinary group in which asset management issues are periodically discussed.

Some authors can argue about the direct link between multidisciplinary group and maturity of asset management but, according to our definition of PAM[12], to optimally manage the whole life-cycle of the asset we need knowledge from different areas and, hence, multidisciplinary become fundamental: we definitely follow this assumption, which is considered in literature on the majority.

[12] Physical Asset Management is the set of activities that an organization undertake to manage asset during the whole life-cycle, from the design/acquisition phase to the disposal, in order to maximize performances and minimize risks and expenditure.

D.I.2) Is there an asset management group within your organization?

Answer	***Maturity score***
No	*1*
No, but there are specialists dedicated to AM duties	*3*
Yes	*5*

The following question is not directly used in the computation but it is important to understand if this group is multidisciplinary as the good asset management practices prescribe.

D.I.2.1) If yes, which professions are taking part of this group / these specialists? [multiple choice]

- □ *Asset manager*
- □ *Project manager*
- □ *Finance, accounting, costing*
- □ *Lawyers*
- □ *Procurement managers and officers*
- □ *Engineers*
- □ *Logisticians*
- □ *Maintenance personnel*
- □ *General staff*
- □ *Others:*_____

Again, the question D.I.2.2 is used only in a qualitative analysis in order to assess if the asset management group has recognized as a group/function with different responsibilities.

D.I.2.2) Which are the organizational duties for which the asset management group is responsible? [multiple choice]

Asset Management Group	***Fully responsible***	***Contribute to the achievement of the results***	***Not responsible***
Acquisition or development projects			
In-service logistic support and procurement			
Organization-wide asset systems and practices			
Asset status knowledge and reporting			
Strategic assessment and development			
Sustainable development (economic, environmental, social issues)			
Other:_____ _____			

D.II) Culture

This part of the questionnaire takes as starting point a previous work done in Australia by Brunetto and Xerri (2012). In their work the authors developed a survey about Culture Asset Management and asked to all people within the company to fulfill it with the aim to examine attitudes and beliefs of employees about AM and to provide information that could be used to improve total asset management strategies. As our questionnaire has different aims, it will be addressed specifically to asset managers. However, we found very useful ideas in their work about some aspects of culture asset management such as roles, policies, training, and communication.

Next question regards the definition of policies and goals. Three different approaches can be identified that a company can choose to make policy decisions:

- Top down approach
- Bottom up approach
- Shared process

The top-down approach to policy decisions, also known as autocratic leadership, is the process of upper management or the chief executive officer reaching independent conclusions that change or improve the workplace or business systems. Lower-level managers can have some input into recommendations for their sections or contribute department data, but the top-down approach does not give them authority to make any decisions. This approach does not provide discussions between top management and employees, and it also saves the company time in explaining why the ideas of some staff members are used and not others. Businesses that are heavily regulated or have many legal issues to consider may find this style of management to be an advantage to them.

Alternatively, bottom-up process of implementation is the opposite of the top-down approach. Employees are the impetus for change in the bottom-up style (Deeb, 2012).

Both approaches have advantages and disadvantages. We think that a shared process has to be preferred because company may include suggestions from employees before formulating final plans and, even if this method can be more time-consuming, it can align goals at the different levels of the organization.

D.II.1) Policies and goals are defined after a

- □ *Top down approach*
- □ *Bottom up approach*
- □ *Shared process*

In D.II.1 we decide to use an opposite approach compare than yes/no question: if the answer will be shared process, we will have “5” while in the other cases we do not consider the answer because as we said before top down and bottom up approaches have advantages and disadvantages and we cannot judge a priori which is the best solution.

Below there are some questions that are not linked to specific practices but are interesting to understand how organization explain policies and the attitudes of the employees regarding changing.

D.II.2) Asset Management policies and employees' attitudes:

ASSET MANAGEMENT	***Strongly disagree***	***Disagree***	***Agree***	***Strongly agree***
Policies are explained in a clear way				
Policies are understood at all levels of the organization				
Changes, and their causes/motivations, in policies are explained in a clear way				
Workers are opened to changes				
Organization motivates workers to changing				
Employees try to give new ideas				

D.II.4) How does company give supports to understand policies? [multiple choice]

- □ *There are no formal supports*
- □ *The company explains the policies through events (such as conferences, workshops)*
- □ *There are documents that explain questions*
- □ *There is a person responsible for implementation*

Events, documents and responsible are supports that help people in a different way. A company with high maturity uses all of them. We decide to assign "4" instead of "5" if the respondent indicates all of them because there is no connection with the continuous improvement that characterizes the "5" maturity level. Conversely if the company does not use any support the score will be "1", while in case of only one support the score will be "2" and then "3" if the supports utilized are two.

The Asset management group can included several people so to work effectively it is important that everyone knows which his role without doubts is.

D.II.5) Is there a job description that clarify the roles of people belonging to AM group?

Answer	***Maturity score***
No, there is not a job description	*1*
Yes, there is a clear job description	*3*
Yes, there is a clear job description and there is a periodic check of the alignment between job description and real work	*5*

We fix "3" if there is a job description because we assume that it means that there is a standard practice, while in the last option we assume that the "check of the alignment" is a way to carry on the continuous improvement.

D.III) Training

As we said in the paragraph about Asset Management Culture, training can be considered as one of the criteria to evaluate Culture Asset Management. Hence, here after, we develop a set of questions on this argument. In general, high maturity is reached if the company has a training plan, spend money to this end, provides permanent training, makes periodical checks on the skills.

D.III.1) Is there a plan for provision AM knowledge and skills?

Answers	***Maturity score***
No, there is not a plan for provision AM skills	*1*
Yes, there is a plan but it is not respected	*2*
Yes, there is an effective plan	*4*

D.III.2) Does company spend enough money for training? [single choice]

Answers	***Maturity score***
No, because training is seen as an expense to minimize	*1*
No, even if company understand the importance of training it spends less than it should	*2*
Company provides enough money for training	*4*

D.III.3) Which training is provided to the following different figures in the organization?

HUMAN RESOURCES	***WHICH TRAINING IS PROVIDED TO***			
	NONE	*INITIAL*	*OCCASIONAL*	*PERMANENT*
Technicians about CMMS / ERP / EAM	*1*	*2*	*3*	*5*
Technicians and managers about maintenance engineering	*1*	*2*	*3*	*5*
Technicians and managers, about Health and safety	*1*	*2*	*3*	*5*
Managers about risk management	*1*	*2*	*3*	*5*
Managers about life cycle cost management	*1*	*2*	*3*	*5*

4) Does the company check previous skills?

Answer	***Maturity score***
No, there is not a plan to check skills	*1*
Yes, although there is not a plan to check skills	*3*
Yes, there are periodical checks	*5*

D. IV) Communication

Brunetto and Xerri (2012) emphasized the important of communication during changes, and we think that it is vital also to develop and reinforce a shared culture.

Communication can then be analyzed relating to:

- Communication Mode. It refers to the method used to convey a message from one organizational member to another that can be formal or informal. Relationships based on formal communication are characterized by policies, written memos or organizational meetings and should facilitate the development of informal communication relationships.

  On the other hand, informal communication is referred to as spur-of-the-moment communication, and it is considered to be verbal or face-to-face communication. Informal communication is developed by people who know each other and who will interact to help each other and can be used as a tool to assist in encouraging and facilitating employees/supervisors within an organization to develop social exchange relationships in which to transfer important knowledge to support work-based problem-solving and creativity in the workplace.

  Therefore, it is important that organizations establish effective formal communication networks to facilitate and support the informal communication networks in place to provide employees access to knowledge to assist in solving work-based problems.
- Frequency. Johlke and Duhan (2000) outline that communication frequency can be measured by the amount of contact between organizational members. A higher frequency of communication between supervisor and subordinate is suggested to improve the link between the employee and the organization and it is thought to be correlated with improved employee job satisfaction and firm performance.

In the questionnaire, formal communications are considered in terms of written procedures and meetings.

D.IV.1) Does the company have/use written procedures?

- □ *Yes*
- □ *No*

D.IV.1.1) If yes, are they revised periodically?

Answers	***Maturity score***
Never	*1*
After important events (overhaul, incidents, new machine installation)	*2*
Continuous improvements	*5*

D.IV.2) Does Asset Management group periodically organize meetings regarding asset management issue?

□ *No*

□ *Yes*

D.IV.2.1) If yes, how the frequency of meetings is established?

Answers	***Maturity Score***
After important events (overhaul, incidents, new machine installation)	*1*
With management availability	*2*
With a constant frequency but it can be increased	*3*
With a constant frequency that cannot be increased	*4*

D.IV.2.2) How often are meetings organized?

□ *Once a week*

□ *Once a month*

□ *Every two months*

□ *Twice a year*

□ *Once a year*

□ _____ *[indicate how often]*

The informal communication is assessed in a qualitative way, based on agreement / disagreement opinions collected from the respondent on specific topics.

D.IV.3) Informal communication

	Strongly disagree	***Disagree***	***Agree***	***Strongly agree***
Communication is based only on formal channels				
There is distrust in informal communication				
The organization tries to encourage informal communication				
There is a right balance between formal and informal communication				

A summarizing table for the organization & culture index is shown in Table 4.8

Organization & Culture Index						
		Maturity Score				
D		1	2	3	4	5
I	1	answer.1		answer.2		answer.3
	2	answer.1		answer.2		answer.3
II	1	answer. 1,2				answer.3
	5	answer.1		answer.2		answer.3
	6	answer.1	answer.2	answer.3	answer.4	
III	1	answer.1	answer.2		answer.3	
	2	answer.1	answer.2		answer.3	
	3	m.answer.1	m.answer.2	m.answer.3	m.answer.4	m.answer.5
	4	answer.1		answer.2	answer.3	
IV	1	no	Yes			
	1.1	answer.1	answer.2			answer.3
	2	no	Yes			
	2.1	answer.1	answer.2	answer.3	answer.4	

Table 4.8 Summarizing table – OCIi

And the formula of the OCI (Organization & Culture Index) for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$OCIi = \frac{\frac{\sum_1^2 D.I._{iq_i}}{2} + \frac{\sum_1^6 D.II._{iq}}{3} + \frac{\sum_1^4 D.III._{iq}}{4} + \frac{\sum_1^2 D.IV._{iq}}{4}}{4}$$
$$= \frac{ORGi + CUIi + TRIi + COMì}{4}$$

where:

- q is the index of the question
- D.i.$_{iq}$ is the score obtained by the firm *i* in the question indexed as q
- ORGi is the organization index
- CUI is the culture index
- TRI is the training index
- COMi is the communication index

E) External Coordination Index (ECI)

This column/index of the matrix concerns the relationship between the company and third parties, such as regulators, society and suppliers.

E.I) Regulators

Companies has to interrelate with a lot of types of regulatory requirements, and may approach them by anticipating requirements and interacting with regulators.

E.I.1) How much do you consider regulators that influence your organization?

Answers	***Maturity Score***
Company considers only present rules	*1*
Company tries to anticipate possible future requirements by itself	*3*
Company tries to interact with regulators in order to understand what would be possible future requirements	*5*

E.II) Society

As it said in Chapter 2 of this thesis, PAM is linked to theme of sustainability. The meaning of sustainable development is “meeting the needs of present without compromising the ability of future generations to meet their needs” (Brundtland, 1987). Sustainability issues may be either a relevant part or not/may assume a minor role in strategic plans of the company; alike, the organization may have developed more or less projects targeting sustainability.

E.II.1) Are sustainability issues considered in the strategic plans of the company?

Answers	***Maturity Score***
No	*1*
Yes, but as a minor aims	*2*
Yes, sustainability is one of the main goal	*4/5**

**The maturity score depends also from the answer at E.II.2*

E.II.2) What projects concerning sustainability are you developing in your organization?

- □ *To reduce maintenance costs*
- □ *To reduce environmental impact*
- □ *To reduce water consumption*
- □ *To reduce energy consumption*
- □ *To treat/reduce waste*
- □ *To improve working condition*
- □ *To support community improvement*
- □ _____

E.III) Outsourcing

Service providers often see asset management as a means of extending their service offering (Herder and Wijnia, 2009). Hence outsourcing became an important aspect to analyze in assessing the maturity in PAM practices, having a look / insight on the support from service provides along the whole asset life cycle.

E.II.1) How many contracts do you have? (order of magnitude)

_____

E.III.2) Which service does your organization outsource?

- □ *Design*
- □ *Construction*
- □ *Operation*
- □ *Maintenance* [13]

Focusing on maintenance, maintenance outsourcing consists in externalizing a set of activities, related to execution of maintenance interventions, information management, spare parts management and maintenance engineering, to a third party. Maintenance service providers offer activities that go beyond corrective and preventive maintenance (Kumar et al., 2005).

E.III.2.1) Which services are offered by your maintenance providers?

- □ *Assistance in defining product specification;*
- □ *Assistance during the installation and commissioning phase of a product/system;*
- □ *Assistance in defining the operational strategy;*
- □ *Field service – maintenance tasks;*
- □ *Remote diagnostics;*
- □ *Expert assistance for at site diagnostics and repair;*
- □ *Help desk, online help, telephone support;*
- □ *Advanced training;*
- □ *Logistic support optimization;*
- □ *Assistance in product End-Of-Life management;*
- □ *IT*
- □ *Other:*_____

The previous questions (E.III.1, E.III.2 and E.III.2.1) are important in order to understand if the service providers are integrated along the whole life cycle of the assets (during the design and the operational phases, in defining assets strategy,..)

[13] These are the fields considered in the acronym DCOM (Design, Construction, Operate and maintain) ordinary used in infrastructure assets management.

but they are not linked to a maturity score because we cannot quantify the answers in a numerical result.

To perform the services listed above the sharing of information becomes a key factor.

E.III.3) How does your organization share information with its service providers?

Answers	***Maturity Score***
There is no database shared between company and contractors	*1*
Contractors have their databases and only some information are shared	*2*
There is some shared databases but contracts cannot update them	*3*
There is an integrated database, easily accessible for both parts	*5*

Outsourcing has several advantages but also it brings some risks, that should not be underestimated. The main risks of outsourcing are:

- Hidden costs
- Less flexibility
- Skills erosion
- Contractual problems
- Conflict of interest
- Suppliers problems

These risks are linked to the uncertainties around costs, contracts and future evolutions of markets.

In a multi-provider situation, it can be difficult to assign every firm its responsibilities, because of the strong interactions existing among different firms' work. This can turn into a difficult definition of a good performance scorecard as a basis of an agreement on the level of services offered (such as a Service Level Agreement). Moreover, conflicts can emerge if a provider offers a predefined level of performances and does maintenance itself, deciding how and when to operate on customer's assets: in these situations, there could be done too much interventions, and too short machine parts

replacement periods could be defined, to be sure not to underperform, with consequent high maintenance costs..

Hence, when externalizing some activities it should be better to keep in-house proprietary assets know-how; if not so, the firm cannot leave its counterpart without having a hard worsening of its performances.

E.III.4) Do risk analysis about contractors exist?

Answers	***Maturity Score***
There is no analysis about contractors risks	*1*
Risk analysis are developed only when contractors are chosen	*2*
Periodical analysis about risks are developed but there isn't a standard procedure	*3*
Periodical analysis about risks are developed with a standard procedure	*4*
There is a continuous monitoring of the risks related to contractors	*5*

Company do not have to check only risks but has also to monitor performance of contractors.

E.III.5) Are the performances of service providers monitored?

Answers	***Maturity Score***
There is no analysis about contractors performances	*1*
Occasional analysis are developed	*2*
Periodical analysis are developed but there isn't a standard procedure	*3*
Periodical analysis are developed with standard procedures	*4*
There is a continuous monitoring of contractors performances	*5*

Concerning performance monitoring, one of the contractual instrument used is the Service Level Agreement (SLA). SLA allows the customer to evaluate provider's performances and pay the service in function of them; the basis of this contractual clause is the defining of a Service Level (SL) which must be granted, and then a no-claim bonus system to manage differences between SL and effective outcomes. In this kind of agreements, a fundamental role is played by the requirements specification and the related contract payment structure: to avoid abuses and to incentive the provider to achieve better performance, the requirements specification must be outcome-based, and the outcome must be carefully measured, defining metrics and a KPI dashboard covering all aspects of outsourcing

E.III.6) Do you stipulate SLA (Service Level Agreement) contracts with your service providers?

- □ *No*
- □ *Sometimes*
- □ *Yes*

Table 4.9 shows the possible answer of the external coordination index.

		External Coordination Index				
		Maturity Score				
	E.	1	2	3	4	5
Questions	I.1	answer.1		answer.2		answer.3
	II.1	answer.1	answer.2		answer.3	
	III.3	answer.1	answer.2	answer.3		answer.5
	III.4	answer.1	answer.2	answer.3	answer.4	answer.5
	III.5	answer.1	answer.2	answer.3	answer.4	answer.5

Table 4.9 Summarizing table - ECIi

The formula of the ECI_i (External Coordination Index), for a generic i-th firm, is then expressed as an arithmetical average of all the questions to which a maturity score is assigned, i.e.:

$$ECIi = \frac{E.I.1_i + E.II.1_i + \sum_3^5 E.III._{iq}}{3}$$

where:

- q is the index of the question
- $E.i._{iq}$ is the score obtained by the firm *i* in the question indexed as q.

4.3 Concluding remarks

It is worth underlining the importance to include in each section of the questionnaire some questions that are not linked directly to a maturity score. There questions have the following functions:

- to introduce the argument of subsequent questions, so helping the respondent to understand better what the section is about;
- to help the analysis of the maturity assessment not in automatic way, as with the closed questions, but through considerations and reasoning (leading to a sort of mixed analysis between closed questions and qualitative reasoning).
- to give some suggestions to the respondent, such as about possible uses of some tools (LCC, risk analysis,…).

These functions are completed with the maturity assessment method based on the close questions and scores associated to their answers, as explained during the whole chapter.

Moreover, also the matrix itself is an important tool for the maturity assessment: as it will be seen in Chapter 5, the matrix is going to be used to finally present the maturity achieved in the different indexes by each company studied. The matrix is a summary table, where each column shows the progressive growth of maturity of PAM practices: the correspondent textual description, characterizing each maturity level, synthesizes in fact the main practices achieved at that level, see next table.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspects in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 4.10 Maturity Matrix

Chapter. 5 Testing the model through case studies

Now that both the PAM Maturity Matrix and the questionnaire with the maturity score have been set up, it is possible to test their application. This is carried out through an analysis of five case studies, three of which developed in Dutch companies, while the others in Italian ones.

In this Chapter, the different case studies are presented: in Section **1**, a pre-test on RWS, the Dutch National Highway Agency, is described. This pre-test is developed in order to understand if the results of the new proposed model are coherent with TUDelft model which, as said in Chapter 3, was previously applied and agreed with RWS's people.

In Section **2**, Dutch case studies are described while in section **3** Italian case studies are presented.

The cases studies are developed with a dual purpose:

1. to assess the maturity of the interviewed companies in PAM practices;
2. to understand if the questionnaire – and consequently the model – analyzes the maturity in PAM practices in a complete and clear way (the respondents don't have doubt, the vocabulary used is appropriate, the results are consistent with their beliefs on the actual maturity of their organization, etc….), being applicable both in infrastructure and in manufacturing industry.

More precisely, the case studies concerns one company for the energy infrastructure, one company for the water Infrastructure and two companies from the process sector, with capital intensive plants. In sections **2** and **3** we focus specifically on the first aim, while in section **4** we collect the considerations about the second purpose from all the case studies analyzed.

5.1 Pre – test: RWS

To test for the first time our questionnaire we asked one of the researcher, who developed the TUDelft matrix within the RWS context, to fill in it simulating to be the asset manager of RWS. This pre-test was developed in order to understand if the results of the new proposed model are coherent with the original TUDelft model.

RWS operates and maintains a national road network, a number of primary dikes and waterways. It is not only responsible for smooth and safe flows of transport on the nation's road and waterways, but also for reliable and useful information and protecting the country against flooding and polluted water.

Below the answers are discussed focusing on the methodological aspects of our research, and comparing our results with the original results of the TUDelft model. The comparison is driven by the indexes calculated in our methodology.

Management Decisions Index (MDI)

Table 5.1 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Life Cycle Costs Management	3,1
Asset Risk Management	3,5
Maintenance Management	3,5
Management Decisions	**3,4**

Table 5.1 RWS Management Decision Index

With the numerical result **3,4**, the company is **between the defined level** of our maturity matrix – i.e. "*LCC and risks analysis are developed in standardized way but they only focus on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed"* – and the **quantitatively managed level** – i.e. *"the importance of LCC and risk management is recognized but the analysis are not done in a complete way. Company understand the importance of continuous improvement and is trying to standardize TPM and RCM practices" –.*

If we look at the TUDelft result, part of our index reflects the Infrastructure Management Decisions column of its original matrix. The risk management level was valued at standard and this indicates that the methodologies and tools are available and applied

for critical asset groups but a lot of works need to be done for the full implementation of risk management within the organization (Volker et al., 2012).

Information Management Index (IMI)

Table 5.2 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Information System	2,9
Asset Performance Management	3,3
Information Management	**3,1**

Table 5.2 RWS Information Management Index

Regarding the Information Management Index, and considering the numerical result achieved (i.e. **3,1**), the company is positioned at the **defined level** of our maturity matrix – i.e. *" the importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed" –.*

Again we can check part of our results, comparing them with the Information Management column of TUDelft model. In fact, from (Volker et al., 2012) we know that *"Static and dynamic data of relevant asset groups are registered systematically according to one standard. Data on performance of assets is in most cases directly available but the validity of the dynamic data still needs attention in order to generate reliable performance indicators on a national level. The methodologies and standards exist but full implementation still requires some effort".*

Organization & Culture Index (OCI)

Table 5.3 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Organization	4
Culture	4,3
Training	2,6
Communication	4
Organization & Culture	**3,7**

Table 5.3 RWS Organization & Culture Index

The table reports the numerical results come from the questionnaire considering only the questions directly related to the maturity score. As we said in the previous chapter 4, there are other kinds of question in the questionnaire that can enable to extend the assessment: indeed, the Organization and Culture Index needs further considerations regarding also the qualitative aspects that cannot be quantified in a score, in particular regarding the cultural aspect.

From question D.II.2 we learn that PAM policies are not understood at all levels of the organization. So the high score, for the effect of the score 5 achieved from question D.II.3, is not proper: we can suppose that, even if RWS gives support to understand policies, they are not effective at all levels of the organization.

From these considerations, we decided to integrate the qualitative analysis of cultural aspect and hence assign the maturity level 3,5 at the culture sub-index (instead of 4,3 as achieved using the questions assigned with a score). Hence, the OCI becomes 3,5 (instead of 3,7).

With the numerical result of **3,5**, the maturity level of RWS can be better understood: it is **between the defined level** – i.e. "*PAM is one of the goal of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it*" – and the **quantitatively managed level** of our matrix – i.e. *"PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated*".

The corresponding column of the TUDelft matrix, the Culture and leadership, shows that, relating to the TUDelft approach, the maturity of RWS in this field is at the standard level. In Volker et al. (2012) the authors explain that "*the asset management principles have been positively received and people generally support the overall asset management objectives as being sound and logical. In fact, it helped them to explain what funds are required to deliver a certain performance and risk level. An integrated asset management training program is now broadly available. People are trained in areas such as reliability centered maintenance, risk management, system engineering and life cycle costing. The Infrastructure Maturity Matrix level was set at 'standard'. Although organizational change and trainings were well received, these processes take time to anchor".*

Hence, in our assessment the maturity is higher. Analyzing the answers, it emerges that the TUDelft's considerations are confirmed also by our questionnaire: people are

trained (but not with permanent courses) in risk management, life cycle cost management, system engineering; people support asset management objectives trying to give new ideas, they are open to changes and organization motivates worker to changes. The reason of the different assessment is attributable at the different formulation of the maturity levels. The third level of TUDelft matrix states: "*AM is one of the organization's objectives. Employees follow training about AM knowledge"* while the fourth level says: "*Asset management is generally regarded as one of the principles of organization. All employees know the basic of AM. There is a wide/full range of training available".* From these definitions it emerges that both levels are on a higher maturity levels than our matrix, so it is reasonable that our scores are higher than TUdelft ones.

External Coordination Index (ECI)

Table 5.4 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Regulatory	5
Sustainability	3
Outsourcing	3
External Coordination	**3,7**

Table 5.4 RWS External Coordination Index

With the numerical result of **3,7**, RWS has **fully reached the defined level** of maturity – i.e. "*Company tries to consider possible future requirements in its strategic plans. Risks and performance of contractors are periodically monitored without standard practices"* –, and it's **trying to achieve the quantitatively managed level** – i.e. "*sustainable development is one of the main goal of organization. Risks and performance of contractors are periodically monitored with standard practices*" –.

Our columns/sub-indexes of the matrix reflects both the external coordination and the market approach columns of TUDelft matrix.

The external coordination column regards relationships with third parties like utilities, local governments and the Dutch Railroad Authority. In this aspect RWS shows a high maturity, fourth level for the original matrix of TUDelft model, that is "*The operational planning and activities were communicated in cooperation to the public. The operational planning was matched to public and other relevant stakeholders' interests*

to prevent nuisance as much as possible" (Volker et al., 2012). This description fits well with our definition of the Regulatory PA at the fifth level (*"There is an active interaction with regulators"), hence our higher score (5) is justified.*

The market approach column of the original matrix regards contractors. Concerning this aspect, the maturity achieves a lower evaluation, i.e. at the defined level. From the researchers of the TUDelft we know that RWS is improving the maturity of this index thanks to decision to change former activity based maintenance contracts into performance based maintenance contracts.

Sustainability could not be compared since no column was explicitly defined, for what concern this topic, in the original TUDelft model.

RWS maturity

This first case was developed in order to understand if our results are congruent with the results come from the original TUDelft model. Table 5.5 summarizes our results.

From this case two considerations emerge:

1. the two models consider different aspects, not completely overlapping, hence we could not fully compare all our results;
2. the results that we could compare are similar; in some cases, for example the culture aspects, the different formulation of the maturity level in our matrix causes discrepancies in the assessment of the maturity, so we needed to make some correction, based on answers to questions with no assigned maturity score;
3. as a whole, see the matrix of Table 5.5, our maturity model expresses properly the actual status of the company, as perceived in the beliefs of the researcher interviewed for this pre-test.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspect in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization-understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according to operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 5.5 RWS Maturity Matrix

5.2 Dutch cases: INFRAen and INFRAwt

5.2.1 INFRAen

INFRAen is a Dutch Energy company responsible for part of the Dutch electricity distributions and gas distributions networks.

The company, in managing of its assets, follows the Dutch standard (NTA 8120) based on the British PAS 55 and, as prescribed in them, has the asset management function on the tactical level.

In the following sections we will try to assess the maturity of INFRAen Physical Asset Management (PAM) practices in the four different aspects of our matrix: management decisions, information management, organization & culture, and external coordination.

Management decision Index (MDI)

The Table 5.6 summarizes the numerical results of our questionnaire.

Index	Maturity Score
Asset Life Cycle Management	3
Asset Risk Management	3,71
Maintenance Management	4
Management Decisions	**3,57**

Table 5.6 INFRAen Management Decision Index

With this maturity score, INFRAen has **plenty reached the defined maturity level,** and it is **trying** to improve its practices in order **to reach the quantitatively managed level** of our matrix.

Going in depth to the answers to the questionnaire, we know that INFRAen recognized Life Cycle Management as one of the pillars of physical asset management (PAM), even if the importance of life cycle costs (LCC) analysis is not understood yet by all the people who act at the tactical level. Moreover, LCC analysis are only occasionally performed for some PAM decisions, such as: concerning acquisition and development of projects, identification of better investment options (investment, repair), identification of redundancy of equipment and systems, planning of maintenance programs.

In terms of issues considered, LCC analysis is almost complete – it does not consider only the disposal costs –; further on, LCC considers also aspects related to the efficiency of the assets, such as failure and reliability, capacity and quality of assets, safety and environmental impact. All the information is integrated in an information system that allows people to access easily to data and work more on the level of decision making, elaborating data and enabling decision. Also contractors can access to PAM information systems but they cannot update or insert new information.

The estimates, updated every years, come from the experience of managers and operators, suppliers and sophisticated analysis of historical data based on previous projects.

Relating to the risk asset management, INFRAen uses standardized and certificated process (as we said before, the NTA 8120 standard). In particular, within this process, INFRAen considers different types of risks (operational risks to suppliers and financial-stakeholders risks), in order to provide a support in the following activities / decisions: plan maintenance program, target maintenance budget, identification of better options (investment, repair,..), and also to provide a common communication tool.

The importance of risk analysis is understood by all the company within the strategic and the tactical level, and the assessment considers both qualitative and quantitative analysis. The results of the analysis are showed through the risk matrix, updated by the board level that uses this tool also in order to explain the vision and the strategy of the company; also a risk database in Microsoft Excel is updated by different departments. Another important aspect concerns the sharing of the information with contractors. In fact, within INFRAen, information from contractors are taken in consideration into the risk analysis and contractors can easily access to risk database.

Last but not least, concerning aspects of maintenance management, INFRAen uses both knowledge from experience (of operators and vendors) and sophisticated quantitative tools in redefining preventive maintenance periods and making continuous improvements. Indeed, it performs proactive maintenance: it is trying to standardize TPM practices in the whole organization, and some assets are RCM driven, RCM process are constantly improved according to the feedback coming from the process quality measurements. For the other assets, RCM is performed only recording results on Microsoft Excel databases.

Summarizing, the company presents practices more mature for the risk management and for maintenance management, but due to the not completely structured analysis about life cycle cost management, INFRAen don't fully meet the fourth maturity level (i.e. **quantitatively managed**) of our matrix.

Information management Index (IMI)

Table 5.7 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Information System	4,8
Asset Performance Management	3,7
Information Management	**4,2**

Table 5.7 INFRAen Information Management Index

INFRAen has a high maturity for IMI. In fact, it is at the fourth level, **quantitatively managed level**, of our matrix, thanks to the effective use of information tools that allow managers and operators to have easily access to data and use them to support the decision process.

The company uses SAP system, CMMS and specific software for FMECA analysis and for the management of technical drawings and documents. There is also a frequent use of Microsoft Excel databases, sometimes as a support to decision making – i.e. for budgeting and planning, reliability and maintainability performance assessment, and life cycle cost management –, sometimes as information tools – i.e. for outsourcing and third companies management, KPI monitoring and reporting, risk management –.

The information flow about asset condition is efficient: data are collected in some cases after periodic inspections and in other cases there is a continuous monitoring; then, data are stored in an integrated and easily accessible database, and used in TPM, RCM and other statistical analysis. Moreover, managers can use PDAs tools to support asset management activities.

Regarding the assessment of performance, INFRAen has different types of KPI, from reliability, to availability, safety and health but also KPI about customer satisfaction and training. They are constantly monitored under the responsibility of the different managers of the organization. They are set every year, and sometimes they are changed during the year in order to better align the strategy with the current situation

(considering changes both in external and internal factors). Standard practices to deal with discrepancies between the actual performances and the target performances exist but they affect only sometimes the decisions at all the levels of the organization.

Hence, from all these considerations, we can say that even if INFRAen does not use sophisticated information tools for all the management activities, the effectiveness with which it manages the information allows INFRAen to reach a high maturity score. On the other hand, performance assessment covers different aspects in the organization, and but it does not affect always the decision making at the all levels.

In order to reach the fifth level of our matrix (i.e. **optimizing** level) in the information management index, the company needs to spend effort to improve the performance assessment.

Organization & culture Index (OCI)

Table 5.8 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Organization	5
Culture	4[14]
Training	3,1
Communication	4
Organization & Culture	**4**

Table 5.8 INFRAen Organization & Culture Index

Considering the organization aspect, the correspondent sub-index positions INFRAen at the fifth level, optimized level, of our matrix. As we said before, the AM department in INFRAen is situated at the tactical level, but it affects decisions also at the strategic and at the operational levels. In particular, there is a specific Asset Management group that is part of the risk management department. The AM group is multidisciplinary: it includes asset manager, project manager, finance, accounting and costing disciplines, lawyers, procurement manger and officers, engineering, maintenance personnel as well as general staff. The AM group has then fully responsibility of the acquisition and development of projects, knowledge and reporting of the asset status, strategic

[14] As explained in the section 4.1 this index considers different qualitative aspects that cannot be translate in a direct maturity score. Hence from the analysis of the qualitative questions we decide to increase the direct maturity score from 3 to 4. In the text we explain better why.

assessment and development. It also contributes to the achievement of the results in in-service logistic support and procurement and in sustainable development. So we can say that the AM department contributes to a large number of projects and has relations with almost all the other departments. In particular for the development of new projects the AM group has to deal with the other departments, such as finance, procurement... in order to understand which can be the possible consequences and to identify the best option.

Regarding the culture aspect, we have to do some considerations. If we consider only the questions related to the maturity score, we know that goals and policies of AM are defined by the board of directors, basing the strategy on the performances achieved in the previous year at the operational level. There is then a job description for people belonging the AM group, although this description is not particularly clear in all the aspects.

From these answers the maturity score should be 3 (defined level, being "*AM one of the goal of the organization*"). However, from the qualitative questions not associated to maturity score, we know that policies are explained in a clear and effective way, though different types of supports such as written documents, events and people. Workers are open to changes and try to give new ideas encouraging by the organization. Also the respondent points out that INFRAen spends a lot of effort in developing a share asset management culture as "*AM is one of the main goals of the organization*". Hence from these considerations, we rescale the maturity assessment, assigning the maturity score 4 to the culture index (quantitatively managed level).

For what concern the training aspect, the company understands the importance of training and provides enough money, but even if there is a plan for provision AM knowledge and skills, it is not always respected. Moreover, in some skills such as CMMS and enterprise system, maintenance engineering, health and safety, training is only occasional; while for managers training on life cycle cost management is only initial: it is worth underlining that this aspect is clearly linked with the low maturity of the company in the LCC analysis, as we discussed in the first section (i.e. for what concern maturity in MDI). For all these reasons, training results at third level (defined level) of our maturity matrix.

Last but not least. INFRAen recognized the need of communication inside the AM group and between the AM group and other departments, both through informal and formal channel. Regarding the formal communication, it has written procedures that

are continually improved. The AM group also organizes once a month meeting to discuss issues about AM decisions. For all these reasons, communication results at fourth level (quantitatively managed) of our maturity matrix.

Summarizing, we can say that AM is part of the organizational culture, but there are some deficiencies, such as the absence of a clear job description or the lack of a structured and efficient plan for training. These are some reasons for not allowing the company to reach the fifth level of maturity of our matrix, while achieving certainly the fourth (**quantitatively managed**).

External coordination Index (ECI)

Table 5.9 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Regulators	5
Sustainability	5
Outsourcing	4,4
External Coordination	**4,7**

Table 5.9 INFRAen External Coordination Index

For the service delivered, electricity and gas distribution, INFRAen has to deal with a lot of regulatory requirements which change during the time. In order to fulfill these requirements, understand possible future requirements and consequently define the best strategy, the company tries constantly to interact with regulators.

Sustainability is one of the main goals of the company. INFRAen is developing projects to reduce maintenance costs, environmental impact, energy consumption, improve working condition and support improvement.

For what concern outsourcing, INFRAen has only one direct contractor which in turn outsourced services and has different contractors. Depending on the assets, then maintenance, design and construction are done by INFRAen or are outsourced. The maintenance service providers offer different services such as:

- assistance in defining product specification;
- assistance during the installation and commissioning phase, field service;
- expert assistance for at site diagnostics and repairing;

- help desk, on line support and telephone support;
- logistic support optimization;
- IT tools.

Hence the service providers interact during the whole life cycle of the assets from the design to the operational phase. As we said before, within the IMI analysis, INFRAen knows the importance of sharing information with third parties; in fact it is trying to create an integrated database, easily accessible for both parts. However we have to note that there are still some parts of the shared database that contractors cannot update.

The high maturity of the company for outsourcing can be seen also by the periodical and standardized analysis, developed about contractor risks, and by the continuous monitoring of the contractors performances: to this last regard, it is worth underlining that Service Level agreement contracts are used to make the control more effective and efficient.

Globally, the ECI is close to reach the best level of maturity, i.e. **optimized level** of our matrix.

INFRAen maturity

The maturity of INFRAen in the asset management practices is quite high, on the average it is at the fourth level of our matrix: this means that the process are quantitatively managed in accordance with agreed –upon metrics. In some aspects, the company is also trying to increase its maturity, applying the principle of the continuous improvement, hence reaching as a result the fifth level, optimized level, of our maturity matrix.

The Table 5.10 shows all the indexes and resumes the maturity of INFRAen.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspects in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 5.10 INFRAen Maturity Matrix

5.2.2 INFRAwt

INFRAwt is the Water Company in the area of Amsterdam and surroundings. It supplies drinking water from the tap, and ensures the discharge of waste water, maintains the water level and keeps the surface water clean.

The company is not following any standards about asset management practices, but it wants to introduce soon the PAS 55.

In the following sections we will go in depth in the assessment of the four aspects of our matrix.

Management Decisions Index (MDI)

The Table 5.11 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Asset Life Cycle Management	2,1
Asset Risk Management	3,3
Maintenance Management	3
Management Decisions	**2,8**

Table 5.11 INFRAwt Management Decision Index

An in depth in the three aspects is needed to motivate the scores so far achieved.

Life cycle costs analysis are used for different purposes in INFRAwt, such as: as a support in acquisition and development of projects and in the evaluation of investment options; for design, retrofitting and optimization of system; for planning maintenance programs.

Considering the type of costs taken into consideration by the firm, at a first sight it seems that the LCC analysis is quite complete. Going more in depth, while trying to understand why the maturity of the company in this column is so low, the situation that emerges is that INFRAwt considers different types of costs and voices of effectiveness, but these data are not collected with a constant frequency and in a structured way. Moreover, the information system is not integrated, data are dispersed and there is not the sharing of databases about life cycle costs with contractors. Instead of this, contractors have to deliver information to the project leader, who later will update them

in the PAM information system. Hence, it can be concluded that the LCC analysis is not really effective for decision making, and it is time consuming.

Regarding Risk management, the maturity is a bit better. In fact, INFRAwt spends a lot of effort in risk management and has different department responsible for it (safety, project, production, asset management department). The importance of risk management is understood both at operational and tactical department, but not by all people acting at these levels.

The results of the risks analysis are used for different aims: to provide a common communication tool, to support process system design and retrofitting, to identify redundancy and also to identify training requirement. Another interesting use regards planning maintenance. In fact, from the assessment of the risks of assets, the company develops a "maintenance concept" through which managers try to understand the effects of postponing preventive maintenance or do corrective maintenance. If the risks are not acceptable, a preventive action is considered in the preventive maintenance plan. Even if the risk management is standardized in the organization, also regarding this aspect the information is not shared in and outside the organization: only the asset management and the safety department can update the risk matrix and the contractors do not have access to it, and related risks databases.

For what concern preventive maintenance, INFRAwt uses mature tools (including the maintenance concepts that come from the risk analysis) but it does not perform at all the TPM practices. Regarding RCM, INFRAwt does not have standard practices but it performs RCM according to the experts' knowledge that act at the operational level and support the maintenance department.

Summarizing, while for the asset risk management and maintenance management the company has fully reached the **defined level** (third level) of maturity, for the asset life cycle management aspect the company needs to spends effort in order to standardize the practices and reach such a level.

Information Management Index (IMI)

The Table 5.12 summarizes the numerical results of our questionnaire.

Index	Maturity Score
Information System	2,1
Asset Performance Management	2,7
Information Management	**2,4**

Table 5.12 INFRAwt Information Management Index

In the previous section, it already emerged that data are disintegrated and dispersed. This is confirmed by the numerical results of the information management section. In fact, with 2,4 as numerical result, INFRAwt has fully reached only the second level of our matrix – **managed** level – and it is trying to achieve the third one.

INFRAwt uses CMMS for budgeting and planning of maintenance activities, for reliability and maintainability performance assessment and for risk management; it has also an EAM for the management of technical drawing and documents. For the other activities, such as KPI monitoring and reporting and life cycle management, it still uses Microsoft Excel tools. But the cause of low maturity is not the tools used but the way in which they are implemented. In fact, the analyst cannot assess all the economic and technical data, so the analysis is poor or almost no existent. Moreover, the company collects and storages data without systematic procedures.

Regarding the KPI assessment in particular, managers do not really understand yet the importance of performance monitoring, and the performance analysis impacts only sometimes on the decision process. Another aspect that needs to be improved regards the frequency of monitoring: in fact, a standard frequency to monitor performances is defined only for some of them while for others they are calculated without systematic practices.

Hence, as a whole, the company needs to work a lot in order to standardize the practice around information management, so to reach at least the third level.

Organization & culture Index (OCI)

The Table 5.13 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Organization	2,5
Culture	3[15]
Training	3
Communication	4,5
Organization & Culture Index	**3,25**

Table 5.13 INFRAwt Organization & Culture Index

For what concern the organization, even if asset management is one of the goal of INFRAwt strategy, it is not in placed at the strategic level and it is only in part of the operational level. There is an AM group but only the asset manager and maintenance personnel are taking part of it. This small group (not multidisciplinary as should be) contributes to the achievement of the results in the acquisition or development of projects, in organization wide asset systems and practices, in asset status knowledge, reporting and sustainable development, without being fully responsible for these activities.

Looking at culture aspect, policies and goals are defined through a shared (very long) process. The organization tries to explain them in a clear way, but they are not always understood at the all levels of the organization (supports exist, such as documents, events and people but they are not so efficient in achieving results). Workers are not open to changes, maybe because also organization does not motivates them to changes.

For what concern training, there is no plan for provision of AM skills, and training is just occasional, being only training about health and safety a permanent issue.

The need of communication is well understood by the company, that tries to encourage it also through informal channels.

As a whole, OCI reaches a **defined level** of maturity, mainly because of weaknesses in the organization aspect. It is worth underlining that communication is not aligned with the actual level reached by other aspects, being – we can say – "oversized" with respect to them.

[15] As for INFRAen, the numerical result is modified. In this case, the maturity score (4) is decreased.

External coordination Index

The Table 5.14 summarizes the numerical results of our questionnaire.

Index	Maturity Score
Regulators	5
Sustainability	5
Outsourcing	3
External Coordination	**4,3**

Table 5.14 INFRAwt External Coordination Index

INFRAwt has a lot of regulatory requirements to consider in its plans and for this reason it tries to anticipate possible future requirements both by itself and by the interaction with regulators.

Sustainability is one of the main goals and, in this respect, INFRAwt is developing projects to reduce maintenance costs, environmental impact, water and energy consumption, waste and also projects to improve working condition and to support community improvement.

Concerning the last aspect of our maturity assessment, outsourcing, INFRAwt has more than one hundred of contractors, for maintenance, design and construction. Most of them are temporary, related to a single project. The maintenance providers do not interact during the whole life cycle of the assets but they provides only assistance during the installation and commissioning phase, field service – maintenance tasks and assistance for at site diagnostics and repairing –. Also in this aspect we can see the lack of an integrated information system; in fact there is no database shared between company and contractors.

Summarizing, regarding the assessment of this index, the maturity is in average at the fourth level, i.e. **quantitatively managed**, thanks to the regulatory and sustainability part, but if we consider only the questions about the relationship with contractors the maturity is only at the third level, i.e. **defined**.

INFRwt maturity

The maturity of INFRAwt in the asset management practices is not so high: on the average, considering the four columns of the matrix in the same way, it is almost at the defined level. But we can say that, in the main aspects of PAM, management decisions

and information management, the maturity is still weak, being at the second level of our maturity matrix (managed): so INFRAwt needs to work hard in trying to improve its asset management process.

The Table 5.15 resumes the maturity levels of INFRAwt.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspect in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according to operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 5.15 INFRAwt Maturity Matrix

5.3 Italian cases: PROCvr and PROCpt

5.3.1 PROCvr

PROCvr is the primary Italian chemical company and one of the foremost in Europe. It manages the production and marketing of a wide portfolio of petrochemical products, it has the possibility to use a range of proprietary technologies and state-of-the-art production systems, and a wide-reaching and efficient distribution network. Moreover, PROCvr supplies a product portfolio with well-known brands and a highly customized customer service. This strength is enhanced by its constant commitment to quality and by a sustainable development for the environment and the community.

PROCvr has different sites, not only in Italy but also in Britain, France, German, Portugal and Hungary.

In managing its assets, PROCvr refers to different standards such as PASS 55, ISO and CEN standards about asset management.

Now, as we did for the Dutch companies, we will go in depth in the assessment of the maturity of PROCvr PAM practices.

Management decision Index (MDI)

The Table 5.16 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Asset Life Cycle Management	3,7
Asset Risk Management	3,7
Maintenance Management	5
Management Decisions	**4,1**

Table 5.16 PROCvr Management Decision Index

PROCvr has almost achieved the fifth level of our matrix, i.e. **almost optimized**, if it is considered that the highest score possible for this Management Decisions Index is 4,6. This is motivated by the high maturity in maintenance management, being others – asset life cycle management and asset risk management – any how close to the fourth level.

In managing its assets, PROCvr tries to understand the impact of the present decisions on the whole life cycle of the assets. To this end, Life cycle costs (LCC) analysis are completed and structured, and they consider also aspects related to the efficiency (failures, reliability, capacity, quality,...). The importance of these analysis is understood by all the people who act on a tactical/planning level, but only by part of the people who act on the operational level. Thanks to an integrated information system, people work more at the level of decision making and the results of costs analysis are used for different purposes in asset management decision making, such as: to support acquisition and development of projects; to support process system design, for retrofitting/optimization; to identify better investment options and redundancy in the system, and to plan maintenance programs.

There are persons from more enterprise functions (R&D, maintenance, engineering and technology) with the organizational duty to fill the data/information on the information systems, and they have also to update the information delivered from contractors.

Estimates, used in LCC analysis, are updated every year, and come from experience of managers, operators, project team, suppliers, analysis of historical data but also from more sophisticated tools like parametric techniques based on statistical-distribution analysis of historic databases, and quantitative models developed in order to take into account the random/stochastic nature of events and relying on the use of specialized statistical techniques to “simulate” future decisions.

The high maturity of the company is confirmed also by the answers in the risk asset management section. In fact, risk analysis are developed considering several kind of risks (operational, financial, environmental, reputational, supplier...), and they are done in standardized way. The results of risk management analysis are used to provide a common communication tool; to support process system design/retrofitting; to identify better investment options, and redundancy in the systems; for spare parts and training requirements; to plan maintenance programs; to quantify maintenance commitment CSFs (critical success factors) and KPIs (Key Performance Indicators); to provide a basis for system modeling and, last but not least, to define the insurance premium.

The company spends a lot of effort in risk management: its importance is understood by the asset management team, by the safety department, by part of the people who act on the operational level and by part of people at the tactical level. The industrial direction is the function responsible for risk analysis, but there are also other functions

that have the organizational duty to update the risk matrix (semi quantitative matrix, ALARP - As Low As Reasonably Practicable - type), such as the Health Environmental Safety and Quality (HESQ), planning and control functions.

Regarding the maintenance management index, the company has the highest score possible, 5. This is because in defining preventive maintenance it evaluates the results obtained with last plan and uses quantitative tools to redefine maintenance periods and to make continuous improvement.

TPM is a standard practice in the company while RCM is performed in the whole organization, trying to constantly improve RCM process according to the feedback coming from the process quality measurements.

Summarizing, PAM practices are mature in the company, reaching a maturity **between quantitatively managed and optimized level**; improvements can be done in life cycle cost and risk analysis in order to fully achieve the fifth level of our matrix.

Information management Index

The Table 5.17 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Information System	2,9
Asset Performance Management	3,3
Information Management	**3,1**

Table 5.17 PROCvr Information Management Index

Under this index, the maturity resulting from the computation is not so high as in the previous section. If we go in depth to the questionnaire, we know that the company uses ERP systems for most of the management activities analyzed, except for the reliability and maintainability performance assessment, for risk management and life cycle cost management, for which spreadsheets (Microsoft Excel) and databases are adopted. The procedures in the ERP system are updated regularly, as results of continuous improvements, and there are professional analysts able to analyze technical and economical data.

Data about assets condition are collected through continuous monitoring and they are used in TPM, RCM and statistical analysis, but they are stored in different databases

not shared by separate functions: these aspects decrease considerably the maturity of the company.

Concerning the other aspect of this index, importance of performance measurement is understood by all levels of the organization, most of all by boards of directors and managers. The KPIs related to PAM used in PROCvr consider the main aspects, such as reliability, availability, maintainability, safety, health, safety, quality of the business results, economics, employees satisfaction and training. They are periodically monitored (a standard frequency is defined, depending on the type of KPIs the range is from 3 to 12 months), and their targets are set with the same frequency. Standard procedures exist to deal with discrepancies between the actual performance. Target and analysis of discrepancies affect decision at the all levels of the organization.

At the end, considering all these considerations, we can say that the results coming from the computation are lower than the ones expected by the interviewee. Indeed, the maturity of the company is supposed to be more at the fourth level for some issues: for example, we know from question B.1.6, that there is an integrated information system that allows people to work more at the level of the decision making, even if – weak point – there are databases about assets condition, not shared by different function (C.I.5); we know also, from question C.II.7, that the performance management work effectively affecting the decision process even if KPIs are not continuously monitored (C.II.3). Considering these answers, as principal ones for adequate decision making (i.e. giving them a kind of “prioritized weight” with respect to others), the maturity level may be higher than the overall numerical calculation shown in the previous table. This was finally achieved after the interview, so fixing a position at **quantitatively managed** level of our maturity matrix.

Organization & culture Index (OCI)

The Table 5.18 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Organization	5
Culture	5
Training	3,5
Communication	4
Organization & Culture Index	**4,4**

Table 5.18 PROCvr Organization & Culture Index

As we can see from the numerical results PROCvr has a very high maturity in the Organization & Culture Index.

In fact, for what concern the organization aspect, it has an asset management function in place at all levels of the organization (strategic, tactical, operational) and it has an effective asset management group, very multidisciplinary and with full responsibilities on different activities, such as acquisition and development of projects, service logistic support and procurement, asset knowledge and reporting, strategic assessment and development, sustainable development and premium insurance definition support.

About the culture, policies and goals of AM are defined after a top down approach; then they are explained in clear way through different types of support (event, written document, people). Workers are open to changes (and the organization motivates them to changes) and they try to find new ideas. Last but not least, people who belong to the AM group know their organizational duties thanks to a clear job description. The company periodically checks also the alignment between job description and real work.

Training is the process area of this index with lower score. This is because, even if the company provides enough money for training, this is still occasional.

Eventually, company understand the importance of communication, and it has written procedures, that are continuously improved, and it organizes meetings regarding asset management issues but only once a year, so the frequency can definitely be increased. However, the communication is not based only on formal channel, and there is a right balance between formal and informal communication.

Hence, after all these consideration, we can say that the high score resulted from the computation is confirmed by the interviewee, and the company is at the fifth maturity level in the organization and culture index (**optimized** level).

External coordination Index (ECI)

The Table 5.19 summarizes the numerical results of our questionnaire.

Index	Maturity Score
Regulators	5
Sustainability	5
Outsourcing	4,4
External Coordination	**4,7**

Table 5.19 PROCvr External Coordination Index

PROCvr has a high maturity also in this last index.

Going in depth in the process areas, the company tries to interact with regulators in order to understand what could be possible future requirements.

Sustainability issues are considered in the strategic plans of the company as one of the main goals. PROCvr has developed different projects in order to reduce maintenance costs, energy and water consumption, waste and the environmental impact but also in order to improve working condition and to support community improvement.

PROCvr has about one hundred contractors: it outsources maintenance, design, construction and HESQ (health, environmental, safety and quality). Maintenance providers are integrated in the whole life cycle of the assets, they offer assistance in defining product specifications and operational strategy, they provide a support during the installation and commissioning phase and in product End-Of-Life management. Moreover, they provide field service regarding maintenance tasks, remote diagnostics, expert assistance for at site diagnostics and repair; help desk and online and telephone support; advanced training; logistic support optimization and IT support. Third parties management is eventually developed through the continuous monitoring of the risks and performances of contractors.

Summarizing, the company has fully achieved the fifth level – **optimized** level – of the External Coordination Index. A critical aspect that emerged also in the management decision area, concerns the sharing of the information with third parties. In fact, there are no databases shared, but contractors have to deliver information, and then a dedicated person/team has to fill in the PROCvr information system.

PROCvr maturity

The maturity of PROCvr is very high, between the forth and the fifth level of our matrix (as Table 5.20 showed).

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspects in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performances of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performance of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 5.20 PROCvr Maturity Matrix

5.3.2. PROCpt

PROCpt is, internationally, one of the most important companies in the field of metallurgy of non-ferrous metals for both production values, and the level of technological systems developed with wide use of process automation and computerization of operations. Moreover it is leader in Italy in the production of lead and zinc.

The company in managing its assets does not follow any standard, and as we will see in the next sections its maturity in PAM practices is quite low.

Management decision Index (MDI)

The Table 5.21 summarizes the numerical results of our questionnaire.

Index	Maturity Score
Asset Life Cycle Management	2,3
Asset Risk Management	3
Maintenance Management	2,3
Management Decisions	**2,5**

Table 5.21 PROCpt Management Decision Index

Regarding the first aspect of our matrix, management decision, the company is only at the **managed level**. Now we will go in depth in the questionnaire to understand from which points this result comes from.

Cost analysis are used for different purposes, such as acquisition and development of projects, support process system design, retrofitting and optimization, identifying of best investment options, identifying of redundancy in equipments and systems and plan maintenance programs. However, this analysis is not developed in a structured and complete way (for example, they do not consider disposal cost and R&D and design costs for asset designed by internal functions of the organization). Further on, data / information used in cost analysis are stored in a partly integrated information system, so a manual integration is present but the effort is claimed to be limited.

Estimates come from simple tools based on the average of historical data, previous project, experience of managers and operators. Moreover, there is not a shared database for data about life cycle management: contractors have to deliver information to a team with the organizational duty of updating the information system.

Risk asset management does not cover all the risks, and there is a standardized process for assessing the main risks. Risk analysis are used to provide a common communication tool, to support process system design and retrofitting, to plan maintenance programs, to identify spare part requirements and to identify better investment options. Even if the importance of risk analysis is understood by part of the people who act on the operational and tactical level, there is no responsible for it.

In managing risks, PROCpt uses a software, called *Cura Software*, as support. Data are updated every year, by a dedicated team belonging to the planning and control department.

For what concern maintenance management, preventive maintenance is performed in a sophisticated way, evaluating the results obtained with the last plan and using quantitative tools to make continuous improvements. However, proactive and reactive maintenance approaches (such TPM and RCM) are not performed in the company: this is the weakest point leading to the numerical value shown in the table.

As a whole, the different weakness at the end motivates the **managed level** of maturity reached by the company for this index.

Information management Index (IMI)

The Table 5.22 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Information System	2,5
Asset Performance Management	2,3
Information Management	**2,4**

Table 5.22 PROCpt Information Management Index

Also the information management index is low, reaching only the **managed level**.

The company uses information system as a support in the management activities, but information is not integrated and there are different databases about asset conditions not shared by the functions. Moreover, analysis about assets data are developed only occasionally without standard practices.

For what concern the importance of monitoring performance it is strongly understood by organization, but the KPIs assessment covers only the main aspects (reliability,

availability, safety, health, economics) and omits other important indicators, such as maintainability, environmental impact, training, employ satisfaction and customer satisfaction. KPIs are monitored with a standard frequency by different department (i.e. maintenance, environment and security, planning and control), but the targets are settled only after important events, such as overhaul, incidents, or new machine installation.

Organization & culture Index (OCI)

The Table 5.23 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Organization	3
Culture	1,5
Training	3
Communication	3
Organization & Culture Index	**2,6**

Table 5.23 PROCpt Organization & Culture Index

The low maturity of PROCpt is confirmed – as **managed** level, but **trying to reach** the **quantitatively managed** level – also for what concern this index.

Focusing on the organization, AM function is in place only at the strategic and tactical levels, not at operational level. Further on, there are specialists dedicated to AM duties, but they do not belong to an effective AM team/group.

The culture is the weakest point in OCI. AM policies and goals are defined after a top down process and then they are explained in a clear way through events (conferences and workshops). But, even if the company tries to motivate workers to changes, they are not opened and proactive to change. Last but not least, there is no job description that clearly defines organizational duties.

The company understands then the importance of training, but it spends less than it should and, moreover, there is no plan for provision AM knowledge. Permanent training for technicians and managers is provided, regarding a number of topics: CMMS/ERP, maintenance engineering, health and safety. Instead, regarding risk management training is only occasional while nothing is provided regarding life cycle cost management.

About communication, eventually, we know that the company uses written procedures that are continually improved. Further on, the AM specialists arrange meetings with a standard frequency (once a year, so this frequency can be increased). As a last issue, it is worth observing that the organization tries to encourage informal communication, but there is distrust in it.

External coordination Index (ECI)

The Table 5.24 summarizes the numerical results of our questionnaire.

Index	**Maturity Score**
Regulators	1
Sustainability	2
Outsourcing	3,3
External Coordination	**2,1**

Table 5.24 PROCpt External Coordination Index

The low maturity of PROCpt is confirmed – as **managed** level – also for what concern this index.

The reason for this low maturity can be found mainly in the fact that the company does not spend effort in foreseeing future requirements and considers only present rules.

Moreover, sustainability issues are considered, only as a minor aim. Nonetheless, the company has developed different projects in order to reduce maintenance costs, environmental impact, water and energy consumption, waste, improve working condition and support community improvement.

About outsourcing, the company has a better maturity level. In particular, it has around fifty service providers for maintenance, design, construction and cleaning of the plants. Nonetheless, maintenance service providers are not integrated in the whole life cycle of the assets: in fact, they only offer assistance during the installation and commissioning phase, support in maintenance activities and help desk/online and phone support. Further on: there are not databases shared between the company and the service providers; performances of contractors are continuously monitored; risks analysis are developed only periodically through standard procedures.

PROCpt maturity

PAM is clearly a new concept in the PROCpt context: the company is then quite far from its achievement, and in fact would need to spend a lot of effort in standardizing practices to improving PAM.

Table 5.25 correspondingly summarizes the results of the previous sections.

	Management decisions	Information Management	Organization & culture	External coordination
5. Optimizing	Life cycle cost and risk analysis are applied in a complete and proactive way. Maintenance is planned following the principle of continuous improvement	Information is a central part of integrated decision-making and data are readily available. Performances of process are monitored to support decision making	PAM is an integral part of organizational culture. There is a multidisciplinary asset management group. Roles are clearly defined and communication works efficiently. Training is seen as a fundamental factor for organizational success.	There is an active interaction with regulators; sustainable development leads strategic plans. Risks and performance of Contractors are continuously monitored.
4. Quantitatively managed	The importance of LCC and risks analysis are recognized but the analysis are not done in a complete way. Company understands the importance of continuous improvement and is trying to standardize TPM and RCM practices.	CMMS/ERP/EAM tools are used to simplify the access to data and support management activities. Performance assessment covers different aspects in the organization and affects decision making but not at all levels.	PAM is recognized as one of the main principles of the organization. The importance of training is understood and communicated	Sustainable development is one of the main goals of organization. Risks and performance of Contractors are periodically monitored with standard practices
3. Defined	LCC and risks analysis are developed in a structured way but they focus only on the main aspects of the life cycle of the assets. TPM and RCM practices are occasionally performed.	The importance of integrated and completed databases is understood but it is difficult to find data in them. Standard practices to monitor the main KPIs are developed.	PAM is one of the goals of the organization. Training is occasional. Organization understands the importance of communication and tries to encourage it.	Company tries to consider possible future requirement in its strategic plans. Risks and performances of Contractors are periodically monitored without standard practices
2. Managed	Some LCC and risk analysis are developed but they are at initial stage. Preventive maintenance is planned according to operator's experience.	Information is not collected in structured databases. KPI are monitored without standard practices.	Organization recognized the importance of PAM principles. Training is only during the implementation phase. There is a distrust in communication	Sustainability is a minor aim. Risks and performance of Contractors are occasionally monitored.
1. Initial	No attention to LCC and risk analysis. There aren't standard procedures for maintenance activities.	Data are not integrated and there is a lack of data and performance analysis.	There isn't a shared culture of PAM. Roles and leadership are ambiguous. The importance of training is neglected.	No interaction with regulators and contractors. The importance of Sustainability is not yet understood

Table 5.25 PROCpt Maturity Matrix

5.4 Assessment of the methodological approach

In this section we eventually focus on the second aim of our cases studies, that it is to assess the methodological approach of our maturity model.

The assessment regards three main aspects. We want to check if:

1. the respondents have doubts about the questions, and the vocabulary used is appropriate both for infrastructure and process companies;
2. the questionnaire is exhaustive both for infrastructure and process companies;
3. the maturity scores, resulting from the model, are congruent with the answers given by the respondents.

Starting from the first point, the questionnaire uses a lot of terms from the PASS 55, well known by the asset managers of the company more mature (i.e. INFRAen and PROCvr) but not familiar to the other two companies. Indeed, during these last two interviews, more effort and time were spent for understanding terms and concepts. But, thanks to the support of comments and notes, that were included in the questionnaire, the interviewees were able to understand all the questions. Another specific problem for PROCpt – the only one who answers to the Italian version of the questionnaire – may regard the different presentation, after translation, of specific English terms.

For what concern the second point, the interviewees found the survey very exhaustive: according to their feedbacks, the questionnaire asks questions about the main aspects of PAM, from risk and maintenance management to culture and organizational aspects, and, moreover, overcome the limits of maintenance department. In the field of the infrastructure firms and, in general, in case of more plants can be interesting to add another section about the coordination and relationships between them (for example a source for inspiration to this end can be the internal coordination column of the TUDelft matrix original model). Another interesting issue, resulting from almost all interviewees, is that, thanks to the logic order (i.e. based on increasing maturity) in which the answers are proposed, companies can use the survey to understand themselves, their maturity in PAM practices, and think about possible improvements.

Regarding the third and last point of the methodological assessment, as we explained in the previous sections, sometimes the numerical results were not congruent with the maturity of the company, as this could be globally perceived with respect to our matrix. This happened, most of all, when looking at the culture issue, where the qualitative considerations cannot be easily translated in a score. Hence, unlike the TeSeM model, in which all the answers are directly linked to a score and the calculation of the maturity can be automatized (for example using an Excel spreadsheet), our actual survey was designed for being more open: indeed, the survey needs final considerations in order to confirm the results coming from the simple computation. This means that we can also modify the maturity score and, consequently, the position in our matrix, after confirming results with the interviewee. The modification, of course, should clearly be motivated and agreed with the interviewee, this was done for example in the case of the IMI of PROCvr.

At the end, regarding the final/overall maturity of the company, we showed our matrix to some of the respondents and we asked them to indicate at which level they were, by their opinions. PROCvr and INFRAen reflected our results while the asset manager of INFRAwt placed his company at lower maturity levels in our matrix. For this case, we attributed the discrepancy to the self-criticism for awareness of the lower maturity and for the higher need of improvements.

On the other hand, we preferred not to show the maturity matrix to the respondents of PROCpt. This was done because, correspondingly to the numerical results of maturity assessment, we can consider that in this company the asset management is still too much linked to the maintenance function, and we think that their vision of AM is not yet mature to the point of making a reliable self-assessment.

Chapter 6. Conclusions

In this thesis work a maturity model for Physical Asset Management practices has been developed and tested through five case studies across different companies managing manufacturing plants and infrastructures.

In Section **6.1** the main outcomes of the research are presented as a summary. The results might be the starting point of future possible researches: in section **6.2**, some ideas for improvements and developments are then suggested.

6.1 Research outcomes

The main outcome of the research is the maturity model itself: this is a joint issue of a methodology, inspired by CMMI (Capability Maturity Model Integrated) has theoretical background, together with a matrix; both the two components were adapted for the maturity assessment of PAM practices. This joint issue was thoroughly proposed (in Chapter 4), then tested in industry (see the results of testing phase in Chapter 5). Thanks to the use of standardized and well recognized terms, the maturity model can be applied both in manufacturing plants and infrastructures.

In particular, the model assumes that PAM practices follow pre-defined roadmaps that pass through implementation, standardization and optimization phases. During the implementation phase, processes are not controlled, activities are carried out without systematic procedures, information is not integrated and shared (we are at so called maturity level ML1). Company needs to become aware of this chaotic situation in order to identify inputs (information, resources, knowledge,..) of processes and to manage, at least partially, the processes themselves (so to achieve ML2). Standardization allows then to define repeatable processes (that is ML3): this is the starting point for a further improvement, in order to get to a quantitative management of the physical assets (that is ML4): it is the aware standardization that brings effective and real actions which transform the standards in a way of work based on quantitative management. The optimized process (that is ML5) is the last step of the

roadmap reached when continuous improvement is applied in the company. The previous concepts are summarized in Fig.6.1.

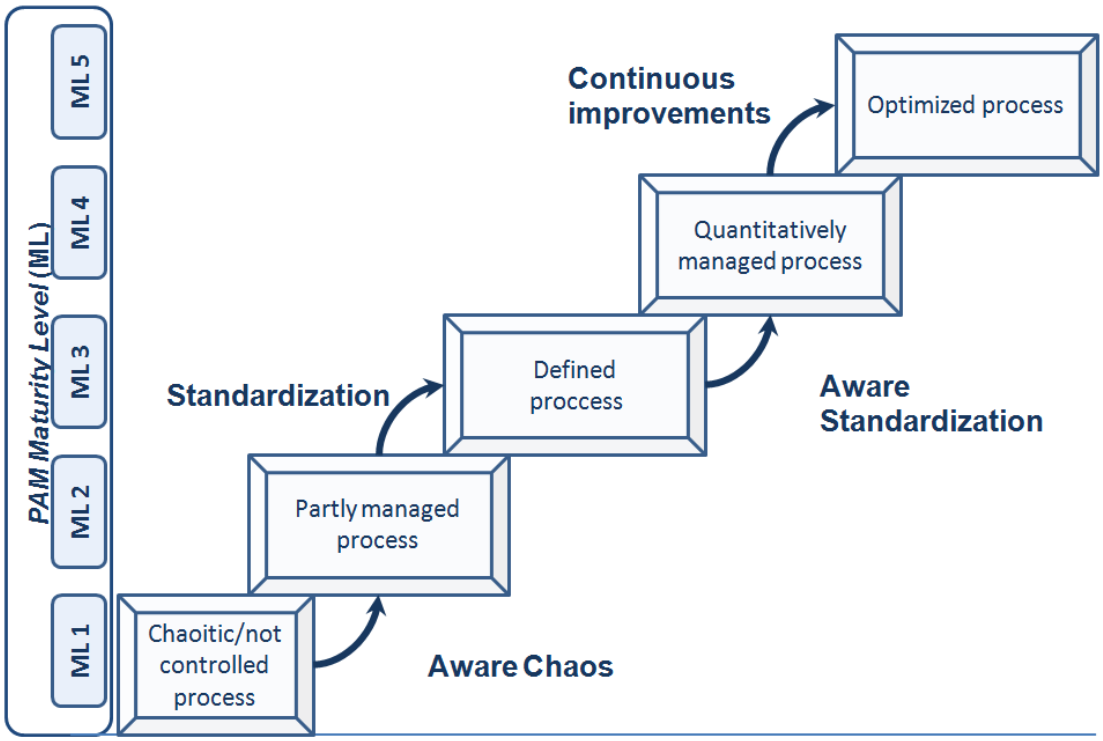

Fig.6.1 PAM Maturity Roadmap

Another outcome, strictly related to building the maturity model, is that a sort of "library" of PAM practices is now available in an unique source. More precisely, it is known that PAM is the set activities that a company undertakes to manage its physical assets during their whole life-cycle. Herein, our model identifies the main PAM practices to do those activities and, moreover, sets for them a roadmap for improvement. According to the CMMI methodology, this is achieved through the pre-defined (maturity) order of the answers in the questionnaire and, then, also through the columns of our matrix, which synthesizes that order.

Concerning the road-mapping issue, it is worth reminding that the order in which the company reaches the maturity levels in each practice (Process Area) depends by its characteristics – for example, as a starting point of improvement, a generic firm can have a high score in LCC (Life Cycle Costing) and a lower score in ARM (Asset Risk

Management) or have a high IMI (Information Management Index) but a lower OCI (Organization & Culture Index) –. Nonetheless, as the holistic view related to PAM affirms, the maturity of the whole company is influenced by the improvement of every PA: therefore, the maturity assessment may be an useful instrument to discuss and prioritize actions, based on a starting point, resulting from the actual maturity of PAM practices in the company.

For what concern the results of the testing phase, in Chapter 5 we obtained the maturity levels for the companies assessed in five case studies. Considering the experience gained during these cases, we may underline that the following aspects increase passing from the lowest mature (PROCpt) to the highest one (PROCvr):

1. completeness and effectiveness of analysis (i.e. life cycle, risk and performance analysis) in order to support management decisions;
2. information sharing (between different hierarchical levels and departments of the organization, but also with third parties);
3. integration of Information System (between different departments and with third parties);
4. sharing of a common culture (between different hierarchical levels of the organization);
5. control of “external factors” (stakeholders, service providers amongst the third parties).

The combinations of these aspects might be the horizontal axis of roadmap described in Fig.6.1 In fact, the five factors listed above represent the key to discern the five maturity levels: depending of the level of integration, sharing and control we will assign a different maturity score to the company assessed.

Last but not least, the definition of the “library” of PAM practices and the characteristics of the designed maturity evaluation (*a priori, survey-like, flexible*) make the model fitted for surveys in different contexts. By filling in a questionnaire, in a relatively short time (the interview lasts about an hour), it is possible to obtain a characterization of the state of PAM practices in a company and, extending the survey in more enlarged contexts, this may be an useful instrument for benchmarking and for the definition of the best PAM practices across different industries.

The survey can be supported by the fact that the companies themselves may find benefit in filling in the questionnaire because (as pointed out in the section 5.4)

the order in which the answers are listed allows to the respondent both to make a self- assessment on his/her organization and to envision what might be the possible developments to improve its PAM practices.

6.2 Future researches

Future works may regard possible improvements of the maturity model. In particular, the maturity assessment proposed in this thesis does not cover the issues and the needs of organizational contexts where more divisions/more plants operate in order to achieve a unique business strategy. Hence, to extend the use of the maturity model, we suggest to add another part about *internal coordination* in which questions may refer to how the different plants or national/regional divisions interact each other (i.e. sharing of information and resources) and to how policies and goals are defined (i.e. definition of targets, budget allocation between different parts of the organization).

Another cue for the study may be to extend the *external coordination* part. In fact, we must not forget that PAM strategy is strictly related to the business strategy: all the operations and maintenance activities are managed to reach the vision of the company and PAM becomes a key factor to achieve business success. In this perspective, more questions about the stakeholders management, such as how stakeholders influence company's actions, how the company tries to understand their requirements, etc…, are important to fully capture the meaning of PAM and to extend the assessment from the tactical to the strategic level of the organization.

The last recommendation regards the use of the maturity model. As said in section 6.1, the main outcome of the research is the model itself that, thanks to the use of standardized and well recognized terms, can be applied both in manufacturing plants and infrastructures. In fact, the experience gained during the case studies has not shown the existence of sectorial barriers in understanding of the specific terms of PAM, even in case of low maturity levels. For this reason we want to *encourage the research along the different sectors* with a dual purpose:

- extend the library of PAM practices;
- Identify the boundary conditions that affect (positively or negatively) the implementation and the optimization of PAM practices.

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Appendix 1 – Questionnaire

Physical Asset Management Questionnaire

Introduction

My name is Chiara D'Alesio and I'm from Politecnico di Milano.

This questionnaire is part of my Master Thesis developed with the collaboration of researches of the faculty of TPM (Technology, Policy and Management) of TUDelft and researchers from DIG (Department of Management, Economics and Industrial Engineering) of Politecnico di Milano.

Why this questionnaire?

It asks questions about the current practice of life cycle cost management, risk management, maintenance management, organization, culture and other important aspects of PAM (Physical Asset Management) with the aim to assess the maturity of the company in PAM practices.

How is it set up?

5 parts with 68 closed questions

A. General Information
B. Management Decision (24 questions)
C. Information Flow (14 questions)
D. Organization & Culture (19 questions)
E. External Coordination (11 questions)

How much time will it take?

About 50/60 minutes

For more information, who contact?

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A) General Information

Company's name:_____

Place of Assets:_____ Country:_____

Corresponding person (name):_____ Function:_____

Email: _____

Sector: _____

> **Physical Asset:** Plant, machinery, property, building, vehicles and other items and related systems that have a distinct and quantifiable business function or service (PAS 55 2008)
>
> **Physical Asset Management:** The set of activities that an organization undertake to manage assets during the whole life-cycle, from the design/acquisition phase to the disposal, in order to maximize performances and minimize risks and expenditure

Do you agree with this definition of physical asset management?

- ☐ Yes
- ☐ No

If No, please, explain why

_____

_____

_____

_____

_____

_____

B) Management Decisions

B.I) Asset Life Cycle Cost Management

These questions relate to the use of cost analysis, such as Life Cycle Cost (LCC), in order to support decision making for Physical Asset Management (PAM)

> A main objective of the LCC analysis is to quantify the total cost of ownership of a physical asset throughout its full life cycle, which includes research and development, construction, operation and maintenance, and disposal.

B.1.1)The results of costs analysis in asset management decision making, in your organization, are used for:

- ☐ Acquisition and development of projects
- ☐ Support process system design, retrofitting/optimization
- ☐ Identify better investment options (investment, repair,..
- ☐ Identify redundancy – equipment and systems.
- ☐ Plan Maintenance programs.
- ☐ Other:_____

B.I.2) Which types of assets' costs does your organization consider to support decision making for PAM?

When assets are acquired by suppliers

- ☐ Purchase price
- ☐ Installation costs
- ☐ Operational costs
- ☐ Disposal Costs
- ☐ Others:_____

When assets are designed by internal functions of the organization

- ☐ R&D
- ☐ Design Costs
- ☐ Installation Costs
- ☐ Operational Costs
- ☐ Disposal Costs
- ☐ Others:_____

Which kind of operational costs does your organization consider?

- □ Energy costs
- □ Planned maintenance
- □ Corrective maintenance
- □ Security
- □ Environmental (carbon footprint, treatment of waste,…)
- □ Lack of production
- □ Others:_____

B.I.3) The importance of cost analysis, in PAM decisions, is understood by [multiple choice possible]:

- □ Only the asset manager
- □ Only the asset management team
- □ Part of the people who act on a operational level
- □ Part of the people who act on a tactical / planning level
- □ All the people who act on a operational level
- □ All the people who act on a tactical / planning level

B.I.4) Is cost analysis, relating to PAM decisions, structured in your organization?

- □ No
- □ Yes, only occasionally, just a cost analysis without making a LCC analysis
- □ Yes, only occasionally, making LCC analysis for some PAM decision makings
- □ Yes, a structured methodology for LCC analysis exists, which is regularly applied for the most important PAM decision makings
- □ Other:_____

B.I.5) In your organization, during cost analysis related to PAM, do you collect data about:

- □ Failures & reliability of asset
- □ Capacity of assets
- □ Quality of assets
- □ Safety
- □ Environmental impact
- □ Other:_____

B.I.6) Are the data from question B.I.5 managed within an integrated information system?

- □ No, the information system providing the data is not integrated; data / information are quite dispersed, manual integration is strongly needed;
- □ Yes, the information system providing the data is partly integrated; data / information are dispersed, manual integration is present but the effort is reduced;
- □ Yes, an integrated information system, providing data / information as a platform, is already present; people work more at the level of decision making (i.e. transforming data / information available to knowledge enabling decisions).

The following questions are related the need to have data/information updated and organized in order to support PAM decision making

B.I.7) Who has the organizational duty to fill the data / information, relating to PAM decision making, in the information system?

- □ Only the asset manager
- □ There are dedicated persons (indicate the functional area of the operators, more than one functional area is applicable:_____)
- □ The asset management team
- □ All the operators can fill the databases (indicate the functional area of the operators, more than one functional area is applicable:_____)
- □ All the operators can fill the databases (indicate the functional area of the operators, more than one functional area is applicable:_____) and there is a check for the consistency.

B.I.8) Where do estimates, used in PAM cost analysis, come from? [multiple choice]

- □ Experience of managers/operators/project team
- □ Suppliers
- □ Analysis of historical data based on the simple average of data
- □ Analysis of historical data based on more sophisticated tools / based on previous projects
- □ Parametric techniques based on statistical- distribution analysis of historic databases
- □ Quantitative models developed in order to take into account the random / stochastic nature of events and relying on the use of specialized statistical techniques to “simulate” future decisions.

B.I.9) Are these estimates periodically updated?

- □ No
- □ After important events (overhaul, incidents, new machine installation, infra projects)
- □ Periodically updated (namely how often:_____)

B.I.10) Sharing information with contractors. Contractors: [multiple choice]

- □ Have to deliver information and there is a person/a team with the organizational duty of update PAM information systems
- □ Can access to PAM information systems
- □ Can update PAM information systems
- □ Can insert[16] data in PAM information systems

B.II) Risk Asset Management

These questions relates to risk asset management

> The purpose of Risk Asset Management is to understand the cause, effect and the likelihood of adverse events which may occur while an asset is managed.

B.II.1) What types of risks does your organization consider?

- □ Operational risks caused by:
  - □ Functional failure
  - □ Incidental damage
  - □ Human factors
  - □ Others:_____
- □ Natural environmental risks (storms, floods,..)
- □ Financial risks
- □ Stakeholders risks (such as failure to meet regulatory performance requirements or reputation damage)
- □ Supplier risks
- □ Others:_____

[16] Insert means that contractors can add new types of information, such as new performance indicators, new information about assets.

B.II.2) The results of risk management analysis are used to: [multiple choice]

- □ Provide a common communication tool.
- □ Support process system design / retrofitting
- □ Identify redundancy – equipment and systems.
- □ Plan Maintenance programs.
- □ Identify spare parts requirements.
- □ Target maintenance budgets.
- □ Identify training requirements.
- □ Quantify the maintenance commitment KSF's, KPI's.
- □ Provide a basis for system modeling.
- □ Identify better options (investment, repair,…)
- □ Other:_____

B.II.3) Is there a risk asset management process in your organization?

- □ No
- □ Yes, but it is not standardized
- □ Yes, but it is standardized for only some risks
- □ Yes, and it is standardized (as an enterprise standard)
- □ Yes, and it is standardized (as an enterprise standard, considering also certifications / norms from third parties / institutions)*

* Specify if there are certifications about risk management process (such as ISO/IEC guide 73/2002)_____

B.II.4) The importance of risk analysis is understood by [multiple choice possible]:

- □ Only the asset/risk manager
- □ Only the asset management team
- □ Safety department
- □ Part of the people who act on the operational level
- □ Part of the people who act on the tactical / planning level
- □ All the people who act on the operational level
- □ All the people who act on the tactical / planning level

B.II.5) Who is responsible for Risk analysis?

- □ There is none responsible for it
- □ Asset Manager
- □ Risk Manager
- □ There is a function responsible for it
- □ Others:_____

B.II.6) Risk assessment is developed through:

- □ Only qualitative analysis
- □ Only quantitative analysis
- □ There is a balance between qualitative and quantitative analysis

B.II.7) Do you have a risk matrix or other similar tool to express, in a visual way, the risk of different entities under concern?

- □ No
- □ Yes (which tool? _____)

B.II.8) Who has the organizational duty to update the risk matrix/risk database required to fulfill the matrix?

- □ Only the manager responsible for it (indicate the functional area of the manager:_____)
- □ There is a dedicated team (indicate the name of the unit / function in the organization: _____)
- □ All the operators can update data (indicate the functional area of the operators, more than one functional area is applicable: _____)
- □ All the operators can update data (indicate the functional area of the operators, more than one functional area is applicable: _____) and there is a check for the consistency.

B.II.9) Are risk data periodically updated?

- □ No
- □ After important events (overhaul, incidents, incidents, new machine installation)
- □ Periodically updated (indicate how often:_____)

B.II.10) Sharing information with contractors. Contractors:

- □ Have to deliver information and there is a person/a team with the organizational duty of update risk database
- □ Can access to risk database
- □ Can update risk database
- □ Can insert data in risk database

B.III) Maintenance Management

PREVENTIVE MAINTENANCE:

Maintenance performed according to prescribed criteria to reduce the probability of failure and the degradation of the asset performance (UNI 10147).

B.III.1) Design of maintenance plan. How do you define your preventive maintenance plan? [single choice]

- □ According to operators' experience
- □ According to operators' experience and vendor recommendations
- □ Using tools of quantitative analysis to define / redefine the best time to do preventive maintenance
- □ Evaluating the results obtained with the last plan and using quantitative tools to redefine maintenance periods/to make continuous improvements

TOTAL PRODUCTIVE MAINTENANCE (TPM)

A proactive approach to maintenance with the objective to improve asset reliability and maintainability, thanks to continuous little improvements with the help of maintainers and production personnel.

B.III.2) Is Total Productive Maintenance (TPM) implemented in your company? [single choice]

- □ I do not know what TPM is
- □ No
- □ Occasionally, we have tried in the past but we did not achieve it
- □ Occasionally, we use TPM practices but not in a constant and systematic way
- □ It is a standard practice in the company

RELIABILITY CENTERED MAINTENANCE (RCM):

approach to maintenance that combines reactive, preventive, predictive, and proactive maintenance practices and strategies to maximize the life that a piece of equipment functions in the required manner

B.III.3) Do you perform Reliability Centered Maintenance (RCM) in your company? [single choice]:

- ☐ I do not know what RCM is
- ☐ No
- ☐ Yes, but only in some department
- ☐ Yes, in the whole organization

B.III.3.1) If yes, how does RCM is performed?

- ☐ Occasionally, recording results on file/documents (ex. Microsoft Excel)
- ☐ Occasionally, recording results on an electronic database
- ☐ It is a standard practice based on software tools for maintenance engineering
- ☐ RCM processes are performed, monitored and controlled (the quality of the process is verified)
- ☐ RCM processes are constantly improved according to the feedback coming from the process quality measurements

C) Information Flow

C.I) Information System

C.I.1) Use of information systems

Which support do you use for the following management activities

	Not performed	In paper	Excel/ Excel + Access	Function of company's ERP[17]/EAM[18]	CMMS[19]	other	Not applicable
a) Budgeting and planning of maintenance activities							
b) Third companies/ outsourcing management							
c) Management of technical drawing and documents							
d) Reliability and maintainability performance assessment							
e) KPI monitoring and reporting							
f) Risk management							
g) Life Cycle cost management							

C.I.2) Is there a professional analyst or an analysis team for the analysis of data concerning asset management? [single choice]

- ☐ No
- ☐ Yes, only for economical data
- ☐ Yes, only for technical data
- ☐ Yes, only for part of economical and technical data
- ☐ Yes, able to analyze technical and economical data

[17] ERP (Enterprise Resource Planning)
[18] EAM (Enterprise Asset Management)
[19] CMMS (Computerized Maintenance Management System)

If you do not have CMMS/ERP system skip to question C.I.4

C.I.3) Review of plans and procedure in the CMMS / ERP / EAM. How often have the maintenance plans or procedures been modified after CMMS / ERP / EAM implementation (excluding updates)? [single choice]

- □ Never
- □ Plan and procedures are loaded into the CMMS / ERP / EAM only after asset installation
- □ Plan and procedures are loaded into the CMMS / ERP / EAM after asset installation and after the occurrence of major events (overhaul, incidents, incidents, new machine installation)
- □ Changes in plans and procedures into the CMMS / ERP / EAM are results of regular improvements leaded by maintenance management

C.I.4) Data on assets condition are collected:

- □ Without systematic procedures
- □ Only after important events
- □ After periodic inspections
- □ Through continuous monitoring

C.I.5) Where does your company storage data about asset condition?

- □ Company does not have a structured database
- □ There are different databases not shared by separate functions
- □ There is a shared database but it is time consuming to find data in it
- □ There is an integrated and easily used database

C.I.6) How are analysis about asset conditions developed?

- □ Analysis about data are poor/almost non existent
- □ Data are analyzed occasionally without a standard way
- □ Data are used in TPM/RCM/statistical analysis *

  * If data are used in TPM/RCM/statistical analysis, indicate the analysis done

_____

C.I.7) Do you use tools such as PDAs (personal data assistant), smart-phone,.. to support asset management activities

- □ No
- □ Sometimes
- □ Yes

C.II) Asset Performance Management

C.II.1) The importance of performance measurement is understood by:

	Strongly Disagree	**Disagree**	**Agree**	**Strongly Agree**
Board of Directors				
Managers				
Operators				

C.II.2) What KPIs related to physical asset management are used in your organization? [multiple choice]

- □ Reliability
- □ Availability
- □ Maintainability
- □ Safety
- □ Security
- □ Health
- □ Environmental
- □ Quality of the business results (quality of products / service…)
- □ Economics
- □ Politics (relationship with stakeholders as regulators..)
- □ Customer Satisfaction
- □ Employees Satisfaction
- □ Training
- □ Others [link them]:_____

C.II.3) Is there someone responsible of KPIs monitoring

- □ Nobody
- □ Every managers
- □ The quality assurance department
- □ Different department (indicate them:_____)

C.II.4) How often do you usually monitor KPIs in your organization?

- □ They are never monitored
- □ They are periodically monitored without a standard frequency
- □ A standard frequency is defined
- □ They are continuously monitored

C.II.5) How often are the targets of KPIs set in your organization?

- □ Only once
- □ After important events (overhaul, incidents, incidents, new machine installation)
- □ Periodically (indicate how often:_____)

C.II.6) Do standard procedures exist to deal with discrepancies between the actual performances and the target performances?

- □ No, discrepancies analysis is not developed
- □ No, discrepancies analysis is occasionally developed without standard practices
- □ Yes, there are standard practices

C.II.7) If discrepancies analysis is developed, does it affect decisions?

	NO	Sometimes	Yes
Of board directors			
Of Manager			
Of operators			

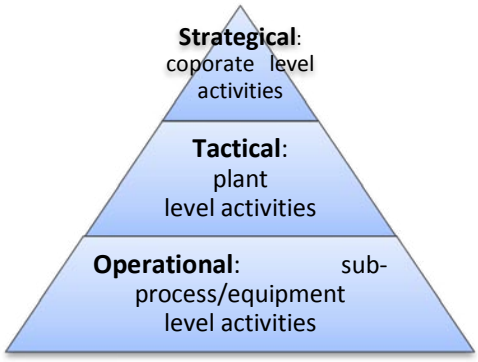
D) Organization & Culture

D.I) Asset Management Function

ASSET MANAGEMENT FUNCTION

The purpose of the Asset Management Function is to provide resources and expertise to support the acquisition/design, in-service support and disposal of the physical assets required by the organization. An asset management function will be needed at company level, providing inputs to asset planning, taking a role in major acquisitions and developments and providing the systems and facilities needed to support assets throughout their life [Hastings, 2010].

D.I.1) At which level is the asset management function in place? [multiple choice]



	Yes	No
Operational		
Tactical		
Strategic		

Asset management group

ASSET MANAGEMENT GROUP

An asset management group consists of asset managers with suitable technical backgrounds, and personnel in accounting and finance, legal, contracting, procurement and engineering roles.
The asset management groups are involved in, and often have primary responsibility for projects of a wide range of types [Hastings, 2010]

D.I.2) Is there an asset management group within your organization?

No

- ☐ No, but there are specialists dedicated to AM duties
- ☐ Yes

D.I.2.1) If yes, which professions are taking part of this group / these specialists? [multiple choice]

- ☐ Asset manager
- ☐ Project manager
- ☐ Finance, accounting, costing
- ☐ Lawyers
- ☐ Procurement managers and officers
- ☐ Engineers
- ☐ Logisticians
- ☐ Maintenance personnel
- ☐ General staff
- ☐ Others:_____

D.I.2.2) Which are the organizational duties for which the asset management Group (the specialists) is (are) responsible? [multiple choice]

	Full responsible	Contribute to the achievement of the results	Not responsible
Acquisition or development projects			
In-service logistic support and procurement			
Organization-wide asset systems and practices			
Asset status knowledge and reporting			
Strategic assessment and development			
Sustainable development (economic, environmental, social issues)			
Other:_____ _____			

D.II) Culture

D.II.1) Policies and goals of AM are defined after a

- □ Top down approach
- □ Bottom up approach
- □ Shared process

D.II.2)

ASSET MANAGEMENT	Strongly disagree	Disagree	Agree	Strongly agree
Policies are explained in a clear way				
Policies are understood at all levels of the organization				
Changes, and their causes/ motivations, in policies are explained in a clear way				
Workers are open to changes				
Organization motivates workers to change				
Employees try to give new ideas				

D.II.3) Does the company give supports to understand policies? [multiple choice]

- □ There are no formal supports
- □ The company explains the policies through events (such as conferences, workshops)
- □ There are documents that explain questions
- □ There is a person responsible for implementation

D.II.4) Is there a job description that clarify the roles of people belonging to AM group? [single choice]

- □ No, there isn't a job description.
- □ Yes, there is a clear job description
- □ Yes, there is a clear job description and there is a periodic check of the alignment between job description and real work

Training

D.III.1) Is there a plan for provision AM knowledge and skills?

- □ No, there is not a plan for provision AM skills
- □ Yes, there is a plan but it is not respected
- □ Yes, there is an effective plan

D.III.2) Does company spend enough money for training? [single choice]

- □ No, because training is seen as an expense to minimize
- □ No, even if company understands the importance of training it spends less than it should
- □ Company provides enough money for training

D.III.3) Which training is provided to the following different figures in the organization?

HUMAN RESOURCES	WHICH TRAINING IS PROVIDED TO			
	NONE	INITIAL	OCCASIONAL	PERMANENT
Technicians about CMMS/ERP / EAM				
Technicians and managers about maintenance engineering				
Technicians and managers, about Health and safety				
Managers about risk management				
Managers about life cycle cost management				

D.III.4) Does the company check previous skills?

- □ No, there is not a plan to check skills
- □ Yes, although there is not a plan to check skills
- □ Yes, there are periodical checks

D.IV) Communication

D.IV.1) Does the company have/use written procedures ?

- □ Yes
- □ No

D.IV.1.1) If yes, are they revised periodically?

- □ Never
- □ After important events
- □ Continuous improvements

D.IV.2) Does Asset Management group / AM specialists periodically organize meetings regarding asset management issue?

- □ Yes
- □ No

D.IV.2.1) If yes, how is the frequency of meetings established?

- □ After important events
- □ With management availability
- □ With a constant frequency but it can be increased
- □ With a constant frequency that cannot be increased

D.IV.2.2) How often are meetings organized?

- □ Once a week
- □ Once a month
- □ Every two months
- □ Twice a year
- □ Once a year
- □ _____ [explain how often]

D.IV.2.3) The importance of these meetings is understood by the organization

- □ Strongly disagree
- □ Disagree
- □ Agree
- □ Strongly agree

D.IV.3) Informal communication.

	Strongly disagree	**Disagree**	**Agree**	**Strongly agree**
Communication is based only on formal channels				
There is distrust in informal communication				
The organization tries to encourage informal communication				
There is a right balance between formal and informal communication				

E) Relations with third parties

E.I) Regulators

E.I.1) How much do you consider regulators that influence your organization?

- ☐ Company considers only present rules
- ☐ Company tries to anticipate possible future requirements by itself
- ☐ Company tries to interact with regulators in order to understand what would be possible future requirements

E.II) Society

SUSTAINABLE DEVELOPMENT

"Meeting the needs of present without compromising the ability of future generations to meet their needs" (Brundtland, 1987)

E.II.1) Are sustainability issues considered in the strategic plans of the company?

- ☐ No
- ☐ Yes, but as a minor aim
- ☐ Yes, sustainability is one of the main goals

E.II.2) What projects concerning sustainability are you developing in your organization?

- ☐ To reduce maintenance costs
- ☐ To reduce environmental impact
- ☐ To reduce water consumption
- ☐ To reduce energy consumption
- ☐ To treat/reduce waste
- ☐ To improve working condition
- ☐ To support community improvement
- ☐ _____

E.III) Outsourcing

E.III.1) How many contractors do you have? (order of magnitude)

_____

E.III.2) Which service does your organization outsource?

- □ Maintenance
- □ Design
- □ Construction
- □ Other:_____

If your organization have maintenance service providers

E.III.2.1) Which services are offered by your maintenance providers?

- □ Assistance in defining product specification;
- □ Assistance during the installation and commissioning phase of a product/system;
- □ Assistance in defining the operational strategy;
- □ Field service – maintenance tasks;
- □ Remote diagnostics;
- □ Expert assistance for at site diagnostics and repair;
- □ Help desk, online help, telephone support;
- □ Advanced training;
- □ Logistic support optimization;
- □ Assistance in product End-Of-Life management;
- □ IT
- □ Other:_____

E.III.3) How does your organization share information with its service providers?

- □ There is no database shared between company and contractors
- □ Contractors have their databases and only some information is shared
- □ There are some shared databases but contractors cannot update them
- □ There is an integrated database, easily accessible for both parts

E.III.4) Do risk analysis about contractors exist?

- □ There is no analysis about contractors risks
- □ Risk analysis are developed only when contractors are chosen
- □ Periodical analysis about risks are developed but there isn't a standard procedure
- □ Periodical analysis about risks are developed with a standard procedure
- □ There is a continuous monitoring of the risks related to contractors

E.III.5) Are the performances of service providers monitored?

- □ There is no analysis about contractors performance
- □ Occasional analysis are developed
- □ Periodical analysis are developed but there isn't a standard procedure
- □ Periodical analysis are developed with standard procedures
- □ There is a continuous monitoring of contractors performances

E.III.6) Do you stipulate SLA (Service Level Agreement) contracts with your service providers?

- □ No
- □ Yes
- □ Sometimes

Suggestions or remarks:

_____

_____

_____

_____

_____

Thank you for your collaboration