Criteria and model for assessing and improving information technology maturity within maintenance

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Abstract. Maintenance optimization and decision-making processes have been both influenced considerably by Information Technology (IT) developments mainly by increasing data availability. The decision-making process in its turn has affected systems trustworthiness positively. Therefore, theoretically speaking it could be said that Maintenance Management Information technology (MMIT) has the potential to provide applicable solutions for many of the maintenance management problems. Nevertheless, this potential has been hardly experienced in practice because of the mismatch between the level of IT maturity in the organizations and their selected MMIT solutions. To fill this gap this paper suggests a number of criteria which are crucial in decision making for selecting a MMIT application. The criteria are formed based on previous findings utilising an extensive literature review. A model is further developed for this purpose which is also tested on a case company active in power generation in Sweden. The model proved to be helpful when taking further improvement steps for reaching high utilization of IT in maintenance.

1. Introduction

According to Kans [1], different Information Technology (IT) solutions for Maintenance Management, hereafter denoted as MMIT, have supported maintenance functions since more than 40 years. Functionalities of MMIT systems have continuously been improved due to the revolutionary progresses in IT. Nowadays, MMIT has a great potential to provide solutions for real and current problems of the maintenance management, however many of the organizations are not mature enough in their IT utilization to take full advantage of these invested potentials. In the view of Matusheski [2], IT provides qualified data availability, which is useful for optimal decision-making in maintenance while availability of qualified data can enhance assets’ reliability. The question is why some companies are successful in MMIT utilization while some others get stuck in taking expected benefits disregard of several attempts? The utilization of IT and MMIT systems depend on the company’s IT maturity [3]. Therefore, IT maturity criteria should be defined enabling the assessment of the IT maturity of an enterprise.

This paper intends to find answers to questions such as how MMIT could assist maintenance management to achieve its goals and which criteria are important to measure MMIT maturity in an enterprise. The paper starts with giving a definition on IT maturity in section 2. Then a model is suggested in section 3 which incorporates a number of suggested criteria. These criteria are further.
explained in details and its contribution in the model is motivated. Further, the model is tested on a
Swedish case company active in the power generation and outcomes are elaborated followed by a
number of practical suggestions in section 4. Section 5 draws some general conclusions regarding the
importance of IT maturity for reaching high utilization of MMIT.

2. IT maturity in maintenance management
Maintenance management is defined as all activities of the management that determine the
maintenance objectives, strategies, and responsibilities and implement them by means such as
maintenance planning, maintenance control and supervision, improvement of methods in the
organization including economical aspects [4]. Referring to the IEC standards [5], maintenance
philosophy is a system of principles for the organization and execution of the maintenance. Crespo [6]
interpreted maintenance strategy into long-term maintenance objectives, which are exemplified as
reaching to the optimal reliability/ maintainability/ availability or ensuring from improving current
situation of an asset. Maintenance tactics are those tactics that a maintenance department may consider
to achieve its strategic objectives. Tactics are subject to the taken strategies and concepts [7].

The IT maturity of the individual and the organization determines the use of IT [8]. Moreover, the
benefit extent gained from technology is dependent on IT maturity level of both the individual and
organization. Employing IT only for daily automation of tasks represents low IT maturity level within
a company; whereas utilizing a large number of mixed high-level strategic decision-making supports
would represent high level IT maturity [3].

Kans continues in [9] that, the more advanced maintenance strategy adopted, the more advanced IT
support is at hand. When applying new IT for supporting more advanced maintenance, one could say
that the maintenance organization has reached a higher level of IT maturity. Foreseeing changes in
current maintenance goal and purposes mean shifting in the strategy applied by the maintenance
organization, which in turn affects the demands on the IT support. When deciding upon IT needs, both
present and future conditions and strategy of maintenance must be considered. Kans confirms that
higher advanced maintenance strategy requires more progressive IT support, which is reflected as a
higher level of IT maturity [8].

3. Proposed model for MMIT maturity improvement
In the following, a model is suggested to shift from lower levels into higher levels of IT maturity in the
companies simultaneous with meeting the maintenance management goals. An overview of the model
is shown in figure 1.

![Figure 1. Proposed model for MMIT Maturity Improvement.](image-url)
The model suggests a number of criteria to measure MMIT maturity. These criteria are used not only to assess the current status of the companies, but also to meet future requirements through higher level of MMIT maturity. The requirements should be aligned with the expectations from maintenance management such as efficiency, effectiveness and cost-effectiveness, which are clarified in the following.

The purpose of maintenance management could be explained by defining overall targets on different levels of control in terms of efficiency, effectiveness and cost-effectiveness [8]. Efficiency is defined as the ability of a maintenance policy to reduce the number of failures, i.e. how qualified maintenance is performed in practice, comprising minimizing all the wastes, costs or excessive efforts throughout the tasks [6]. Kans defines in [8] effectiveness as the ability to use available maintenance resources for maximum benefits while cost-effectiveness is defined as the long-term economical benefits of the maintenance policy and makes a connection between these three maintenance goals and profitability passing through production and company goals, such as equipment availability, process reliability and safety, or product quality. By adopting an effective maintenance strategy, maintenance cost can be controlled; production-related resources can be utilized more while maintenance can contribute in on-time delivery of high quality products. These effects in turn may raise the company reputation and increase the company competitiveness.

The model introduces five criteria to assess the MMIT maturity in an enterprise:

- MMIT utilization level
- Decision making using MMIT
- MMIT integration
- Key Performance Indicator (KPI) monitoring/controlling by MMIT
- Data quality in MMIT

These criteria are presented and discussed as follows.

3.1. **MMIT utilization level**

Computerized Maintenance Management Systems (CMMS), Enterprise Resource Planning (ERP) and Enterprise Asset Management (EAM) solutions are all examples of commonly utilized IT systems for maintenance management. According to [8], most CMMS software are limited administration applications and mainly for short-term maintenance planning at operative level, while ERP systems are suitable for coordination of resources at tactical level. Referred to [10], ERP systems cover nearly all the major areas of an enterprise business like finance, human resource, material planning, maintenance, productions and etc. EAM deals with the management of the total life cycle of assets in enterprises included Investment planning, construction, Operation, Maintenance and disposal of Asset [11]. The type of IT system installed is one dimension describing the IT utilization, but the functionality coverage with respect to the needs of the organization is also an important aspect [12]. For instance if an enterprise has obtained an advance EAM solution but utilizes only a small portion of that, then the IT utilization would still be noted as low.

In another type of segmentation, proposed by Kans and Ingwald in [10], the utilization of IT in maintenance is classified based on the supported maintenance strategies. Stand-alone CMMS with basic functionality are sufficient for Reactive maintenance while having a CMMS with information sharing possibilities with the other IT systems including Condition Monitoring Systems and ERP systems are needed for a Proactive strategy.

In summary, the utilization level could be measured in the amount of IT systems utilized, or in the functionality coverage the IT systems provide. It could also be measured with respect to support coverage, i.e. the extent in which the IT systems support the full maintenance needs, or what kind of maintenance strategy the MMIT utilized mainly support.

3.2. **Decision making support using MMIT**

There exists a relationship for utilizing IT systems for maintenance management with the IT maturity of the organization [8]. Immature organization will be focusing on IT applications to support daily
activities or at operative level working with data collection and storage, and only low amount of analysis and decision making. The author continues that IT mature organizations apply IT applications not only at operative or tactic level but also on strategic level for advanced decision making processes by combining vast amount of data from different sources. These data are used for instance for advanced planning or for continuous improvement, see e.g. [13].

Al-Najjar and Kans highlighted in [14] the importance of relevant data for maintenance decision-making. Cost-effective decisions can only be made using relevant data from different areas of maintenance like maintenance policy, personal competence, training and production. IT development has contributed towards providing effective decision solution for more complex decisions both by shortening the time and provision of easiness. Relevant, accurate, reliable and speedy decision making support is furthermore required. [15] assert that computer aided decision making potentially facilitate decision support as well as decision-making.

The lack of appropriate decision making applications in traditional CMMS has been recognized by for instance [16], while EAM systems provide support not only for operational and tactical maintenance decision making, but also on the strategic level. ERP systems in general provide further supports for decision making, but might lack specific maintenance management perspectives which could in turn affect the total decision process in negative, see e.g. [17]. The decision making could instead be supported by dedicated maintenance decision support systems such as those described in [16] and [18].

3.3. MMIT integration

[13] determine that IT integration is one of the criteria for measuring the IT maturity of an enterprise. They argue that in an organization with high level of IT maturity, high level of system integration is also seen since IT should support activities in all levels (from operative to strategic level) in order to achieve cost-effective goals.

Cost-effective decision making could be achieved by integration, analysis and effective utilization of relevant data, information, databases and knowledge [14]. The integration is not only a technical issue applicable for different IT systems or data sources, but also important in the organization level. To reach the full potential of maintenance, the maintenance department should be integrated with the enterprise, and the IT integration is merely a means to achieve this [10]. Altogether, the extent that the MMIT is integrated with enterprise IT is a criterion for MMIT maturity.

3.4. Key performance monitoring/controlling by MMIT

According to [19], maintenance performance is the result of activity using resources to retain an item, or restore it to a state in which it can perform its required function. This standard reiterates that maintenance key performance standards provide an opportunity for the management to be competitive by utilizing their assets effectively. Crespo [6] believes that KPIs should be aligned with company strategies and be extracted from the deviation between present conditions and the company vision, and [20] expresses that performance indicators in maintenance represent the opportunities for improvement within an organization. Both technical and economical KPIs needed in maintenance decision-making, and propose a method for identifying relevant data from heterogeneous data sources in the enterprise for the creation of such KPIs [14]. MMIT type and level are highly associated with the KPI monitoring/controlling [21] In general, simple CMMS applications lack enough functionality, or provide only simple supports, for creating and monitoring KPIs, while more advanced IT systems includes better data coverage for creating KPIs [14]. To define advanced KPIs, dedicated Business Intelligence systems are often required. The ability to define appropriate maintenance KPIs and align these with the overall business strategy as well as the ability to integrate data from various heterogeneous systems is important for achieving effective maintenance control, see e.g. [10] and [14].
3.5. Data quality in MMIT

[22] explain the data quality as the data fit for their intended uses in operations, decision-making and planning processes. [15] determine that cross-functional decision-making necessitates integrated, highly reliable and readily accessible databases. They indicate that to achieve faster and more accurate decision making, data must be accurate, timely, complete, easily accessed and informative. Some examples of poor data quality such as data errors, poor integrations, inconsistencies, different data formats and unreliable data which lead users into mistakes, lost opportunities, failed deliveries and invoicing problems are given in [23]. They determine that the decisions taken by a company are not better than the data on which they are based; so better data leads to better business decisions.

Obviously data quality will affect while is being affected by the above mentioned criteria. Recognizable is that several of the criteria simultaneously bring positive and negative effects to the data quality. One example is the integrated systems such as the ERP and EAM systems. There, integrated data sources in these systems have positive effects on the data accuracy (because data has not to be entered more than once) and on data accessibility (because the same data could be shared by several users). From the other side, the entered data suffers from standardization making it less informative to some of the users, see e.g. [14].

| Table 1. Levels of MMIT maturity with respect to maturity criteria. |
|---------------------------------------------------------------|
| **Criterion** | Low level of MMIT maturity | High level of MMIT maturity |
|----------------|----------------------------|-----------------------------|
| MMIT utilization level | IT is applied mainly on the operative level taking care of daily maintenance business, for instance in form of simple CMMS or utilising the similar functionality of an ERP system. Mainly reactive maintenance strategies are supported. | Advanced IT systems such as ERP and EAM are applied for supporting maintenance management. The full potential in the MMIT is utilized. Predictive and proactive maintenance is supported. |
| Decision-making using the MMIT | Decision making is supported by IT to low extent or on operative and tactical level alone. Advanced decision support is lacking in the IT system or is not utilized. | Decision making is highly supported by the MMIT either as specific functionality in the IT system, as a dedicated DSS or by integrating several data and IT sources. Decisions on all levels of control (operational, tactical and strategic) are enabled. |
| MMIT Integration | The MMIT is not an integrated part of the enterprise IT architecture and the MMIT is supported to low extent in the IT strategy. Maintenance is seen as a separate function within the business. | Integrated IT solutions are used, and different MMIT could share required data and information. The maintenance is cooperating with other relevant functions in the enterprise. |
| KPI Monitoring/Controlling by the MMIT | Few or no maintenance KPIs are defined and utilised in the enterprise. KPIs are hard to create and monitor using available MMIT, or the KPI functionality is available but not utilised. | KPIs are defined allowing for assessing the maintenance performance on operational and tactical as well as strategic level. MMIT enables automatic and speedy creation and monitoring of these KPIs, utilising the most relevant data sources. |
| Data quality in MMIT | Data quality characteristics are poorly met [or not well employed] during data collection and storage. This leads for instance to poor decision making support. | To achieve faster and more accurate decision making, data must be accurate, timely, complete, easily accessed and informative. Data quality characteristics such as consistency, completeness, real time, timeliness, accessibility, objectivity, are kept during data collection/data storage. |
3.6. Levels of MMIT maturity compared with the maturity criteria
In order to pass from a low level of MMIT maturity to a high level, the basic of judgment could be relied on the level of the above mentioned criteria in the enterprise. Table 1 defines low and high levels characteristics for each of the criteria.

4. Illustrating an application of the proposed MMIT maturity model
The suggested model is in the section applied in a case company, to serve as an illustration of the approach. Given data is collected within a site visit and interview with the maintenance manager of the case company in spring 2011.

4.1. Case company description
The case company is a successful enterprise active in power generation from biomass. They utilize power turbines to generate electricity and district heating for inhabitants of Småland region located in the south of Sweden. All district heating and 25-30% of all the electricity needed by the customers is produced in the two plants. The third plant is currently under establishment to meet increasing demands on electricity and heating within the region. The company includes various departments such as maintenance, design, manufacturing, logistics and product quality. It is known that the company is quite satisfied with its present conditions including budgeting, failure management, marketing and sales as well as data sources and systems. They have had no major shutdown hitherto while the company has been profitable disregard of available domestic competitors. Currently they do not face with any direct competition in the region.

4.2. Maintenance management at the case company
The maintenance is organized in two workshops of the mechanical and the electrical, and both are directed by the maintenance manager. Maintenance and production departments are working tightly with each other. The most frequent failures occur in the boiler where the fuel burns on a bed of sand.

Both corrective and preventive maintenance policies are executed in the company. For critical failures corrective actions are carried out immediately. Non-critical failures are either cured immediately or planned for later action. In addition, visual inspections are carried out on daily basis. Major overhauls are performed once a year. Online monitoring using SPM (Shock Pulse Method) and vibration sensors, as well as yearly oil analyses, are also utilized.

4.3. IT utilization in maintenance at the case company
The company uses an ERP system since 1987 for maintenance and business applications. The ERP system, which is one of the popular ERP applications among the Swedish industries, is originated from a CMMS but developed during the decades into a full-fledged ERP system with considerable production support focus. Every three to four years they upgrade their software. They do not use all features of the software; only 15% of their ERP features are in use. The software has not been recognized as user friendly for instance due to its complicated working procedures, according to the maintenance manager. One example of low user friendliness in the software is the search function.

The main features of the company ERP system utilization in favor of the maintenance management are as follows:

- Work order management: Time based Preventive Maintenance (PM) work orders as well as emergency work orders are manageable and in use. Work orders are closed after a feedback process. Other potentially available modules for maintenance work planning and execution in the ERP system are not in use.
- Maintenance history: A history of the executed work orders is available. In addition, the company has a complete database of all happened failures of their equipment since 1987 hitherto and this is according to the maintenance manager highly reliable.
• Only one access level for all available users in different levels (managers and technicians) is defined in the ERP system.
• The company pays regularly for upgrading and customizing the ERP system while they are not still consent with the system and do not use a number of its modules. Other modules of the ERP system that are utilized by other departments in the company are purchase and invoicing, project management, documentation and time tracking. In addition, the company uses a number of independent systems for various objectives such as budgeting customer administration. Else than the ERP system, there is no IT-base data integration between the maintenance department and the rest of the company.
• For project planning, the ERP project management module is not used by the maintenance department and instead, separate project management software is utilized.

A continuous data measurement system in the control rooms is installed for vital assets (including turbines and main pumps). The turbines are monitored by an online condition monitoring system. Vibration, temperature and leak detection data are collected continuously. This system is run independent from the ERP system. Manual data communication is carried out between production and maintenance. Moreover, they do not strive for database/data source integration, as they do not feel it would be needed at present, simply since maintenance activities are not primarily planned based on the failure history.

The maintenance department does not have defined KPIs. One overall production related performance indicator is used, the cost per megawatt. This KPI is used mainly for benchmarking purposes and not for direct business control. Decision-making in the company is based on the skilled staff and manager’s competency and experience. This experience is also used to handle spare parts, failure management and maintenance activities properly. No decision-making software is in use.

4.4. MMIT maturity level
In the table 2 the company current status is compared with the introduced criteria to extract its level of maturity. The MMIT maturity criteria are discussed in below.

| Criterion | Low level of MMIT maturity | High Level of MMIT maturity |
|-----------|-----------------------------|-----------------------------|
| MMIT utilization level | X | |
| MMIT Integration | X | |
| Decision-making using the MMIT | X | |
| KPI Monitoring/ Controlling by the MMIT | X | |
| Data quality in MMIT | X | |

4.4.1. MMIT utilization Level
It is known that the case company uses just 15% of the ERP software while they pay for regular customizations and updated versions periodically. Moreover, still the case company is not satisfied with the ERP system because it is apprehended as non-user friendly. This means that case company customizations are not efficient and aligned with their real requirements. The used functionality is mainly supporting operational activities.
4.4.2. MMIT integration
Maintenance related data are found in different production monitoring and condition monitoring systems in addition to the ERP system, but these systems are not in communication with each other. When data is intended to be combined, this is made manually. Nevertheless, the maintenance function is well integrated with the production.

4.4.3. Decision-making using the MMIT
The case company does not use the ERP (or any other IT type system) for combining data for complex strategic decision-making purposes. In the decision-making process, since decisions are not highly computerized it is assumed that these decisions are not comprehensively aligned with the maintenance as well as the company strategies and are not mainly cost-effective. Decision-making is being done in rather low level and is based on experience and gut feeling rather than utilizing available data in the company.

4.4.4. KPI Monitoring/ Control by the MMIT
The company is not motivated to define and follow up more than the one KPI currently utilized due to being profitable and having no actual competitor in the regional market. No maintenance related KPIs are used, either manual or defined in the ERP system.

4.4.5. Data quality in MMIT
Data quality is known to be satisfactory considering that the company is quite content with its present data sources and there has been no major shutdowns hitherto. It should be noted that due to having scattered databases, data accessibility and being real time is not in a satisfactory level. In addition, the low user friendliness of the ERP system may cause low data quality.

4.4.6. Suggested solutions to enhance the MMIT maturity
The case company is assessed as IT immature, and suitable enhancements would be to increase the utilization of the current IT system, integrate condition and production monitoring data into the maintenance management system, develop maintenance related KPIs and to implement reports for follow up and improvement. The decision-making could be improved continuously using appropriate MMIT systems. These appropriate MMIT systems should be in a level that could be handled with respect to MMIT maturity level. For instance, a simple system for failure data analysis could be developed, or if the condition monitoring module was supposed to be integrated with the ERP system, complementary analysis modules could be installed also. Suitable KPIs and reports for the maintenance could be defined to assess maintenance costs per produced megawatt, work order handling efficiency in form of amount of backlog and the ratio of corrective to preventive work orders, and the maintenance performance in form of amount of failures compared with total number of PM work orders.

5. Conclusions
Companies may not get their planned benefits from investments in MMIT unless their selected MMIT level is balanced with their IT maturity level. An appropriately selected MMIT can be fully utilized and assists maintenance management to achieve its goals based on efficiency, effectiveness and cost-effectiveness. Therefore, an appropriate selection of MMIT can increase the company profitability directly and indirectly.

The proposed criteria (i.e. MMIT utilization level, decision making using MMIT, MMIT integration, KPI monitoring/ controlling by MMIT and data quality in MMIT) could be used to evaluate the maturity level of a company with respect to MMIT. The developed model is helpful when taking further improvement steps towards more return of investment. When the MMIT level has been matched with the maturity of the company and the proposed criteria are fully met, then the company
should be quite successful in MMIT utilization. The criteria should be transformed into measurable variables to capture MMIT maturity levels. The number of and types of maturity levels could also be developed, for instance into a six stage model as proposed in [3] or a three stage model as in [25]. Another future work would be to develop valid measures of the impact of the IT in terms of efficiency, effectiveness and cost-effectiveness.

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