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REVIEWS AND CASE STUDIES

The advancement of maintenance information technology

A literature review

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Abstract

Purpose – Maintenance management information technology (MMIT) systems have existed for some 40 years. The purpose of this paper is to investigate the advancement of these systems and compares the development of MMIT with other corporate information technology (IT) systems.

Design/methodology/approach – This paper is a literature study of 97 scientific papers within the topic of MMIT in the period 1988 to 2003. Additional readings have been made in books covering MMIT.

Findings – The paper finds that the focus of MMIT has changed in several aspects during the 40 years that have been investigated; from technology to use; from maintenance function to maintenance as an integrated part of the business; from supporting reactive maintenance to proactive maintenance; and from operative to strategic maintenance considerations. Advancements in MMIT have in general followed the development of corporate IT.

Research limitations/implications – Further studies to cover application-specific development, for instance the use of decision support systems within maintenance management and to cover literature after 2003, are of interest.

Practical implications – Knowledge about the development of MMIT adds to the understanding of today's computer applications for maintenance management, which is crucial for every maintenance manager using or purchasing MMIT. The findings could be used as a means to identify the future trends of MMIT, as well as possibilities and problems with the new technology, tools, techniques and methods.

Originality/value – Papers dealing with the development of maintenance management IT are scarce and this paper represents the first full review of MMIT so far.

Keywords Maintenance, Computers, Computer applications

Paper type Research paper

Introduction

Research shows that information technology (IT) investments have a positive correlation on companies profitability and competitiveness, thus that IT has strategic importance, see for instance Kini (2002) and Dedrick *et al.* (2003). Moreover, the importance of IT systems for the management of maintenance has been highlighted in Jonsson (1999). Information technology systems have been in use in companies some 40 years and are today a natural tool for many workers. IT systems for maintenance purposes have existed approximately as long as computers have been available for commercial use. Even though, has the development of maintenance management information technology (MMIT) been in pace with the general development of corporate IT? And in what way has MMIT made advances during the 40 years of

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existence? These questions will be investigated using literature as a basis. After reviewing literature about MMIT several times the author has not yet found a literature study describing the development of MMIT. To fill this gap, we will in this paper present a literature review over the topic of MMIT focusing on the development of the concept specifically, and in comparison with the development of corporate IT in general.

Information technology systems within companies; a historical perspective

To be able to understand the development of maintenance management IT, which is the aim of this paper, we will first look at the general computerisation of companies. This section presents three main phases within corporate information technology development; the Introduction, the Coordination and the Integration phase. These phases will be illustrated by looking at the general development of corporate IT in the next section, but first the author would like to briefly define the phases. The phases have been extracted from the six stages of IT growth and maturity defined by Nolan in (4). The theory is based on several studies, which Nolan conducted in the 1970s and is an enhancement of a four-step concept of data processing growth presented in (5). The model describes six stages of information technology growth, from the interception of the computer into the organisation to the mature management of data resources. The initiation stage, when the computer is placed into the organisation, is characterised by a lax planning and control and a centralised IT organisation. Applications are mainly aiming at functional cost reductions. In the contagion stage rapid and uncontrolled growth in the number of kinds of IT applications occur. Top and middle management gain control of, and start standardising, the IT resources in the control stage. Stage one to three mainly concerns the management of the computer. Between stages three and four a shift in focus occurs, from computer management to the management of data resources. In the integration stage, the use of IT increases rapidly, providing new benefits and supporting the overall business strategy. Databases are used for retrofitting existing applications. Data are recognised as important in the data administration stage. In the last stage, the maturity stage, data resources are planned on a strategic level and IT applications are truly supporting the business processes. For simplicity, the six stages have been reduced to three in this study, whereas the first two stages of Nolan, Initiation and Contagion, are similar to the Introduction phase. Here technology and functional automation is stressed. In stages three and four, Control and Integration, the top management gains control over IT resources and the IT resources are supporting the overall business strategy, i.e. for coordination of business activities as in the Coordination phase. The last two stages in Nolan's IT maturity model, Data administration and Maturity, deals with data sharing and information systems as a strategic matter. These stages are similar to the Integration phase (see Figure 1).

Based on this model, a historical review of general corporate IT is given in the following.

Introduction: the emergence of corporate information technology

The use of IT emerged in administration in the 1950s and 1960s mainly to automate information processing, Persson *et al.* (1981) and Dahlbom (1997). The first computers, the mainframes, filled a whole room and special crew fed the mainframe with input

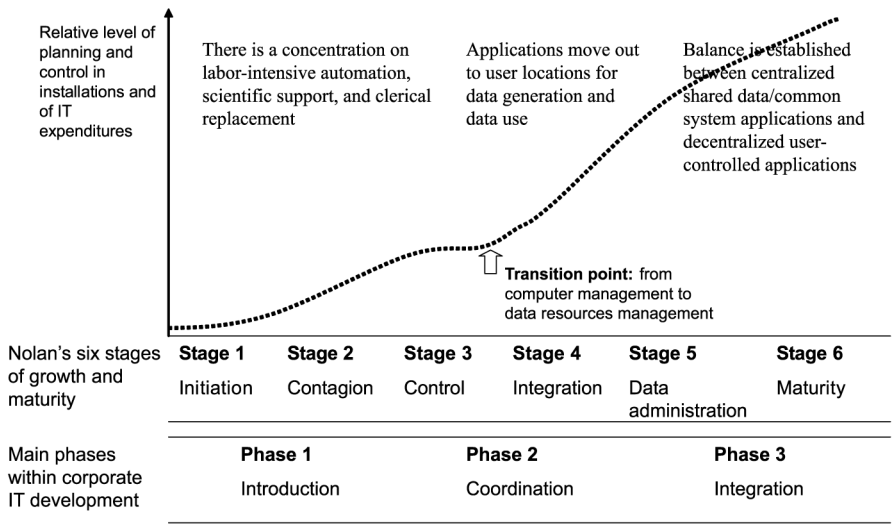

Figure 1.
Corporate IT development

data and programs for, e.g. sorting, listing and analysing payrolls, customer registers, supplier registers and so on. Computing time was expensive and the most crucial calculations and analyses were prioritised. These computers were for the larger companies to use, while the medium and small sized still had to rely on manual information handling. When the mini computers emerged in the 1970s, computer power was accessible for "everyone", Persson *et al.* (1981).

The IT systems that were developed for mini's contained department specific applications. The financial department ran spreadsheets and ledger applications, the management word processors and market analysing applications while the personal administration computed payments and kept a payroll application. Each application structured the information in its own way and data were stored in file systems. Cross-functional access of data and information was not supported. Neither was the management able to get reports including information from more than one area of the business, if not special applications were bought or developed for this purpose, see for instance Mullin (1989).

Coordination: connecting the systems together

In the late 1970s and 1980s the use of middleware, devices that act like a translator between two systems both talking their own language, enabled the communication without actual changes in the specific systems, see, e.g. Tuunainen (1998). With the ability to interchange information between IT systems, the possibilities to coordinate the organisation grew, both in the horizontal and hierarchical level.

The 1980s could be characterised by incorporation efforts. Now all separate IT systems should be incorporated into a unity and this met some problems. For the technical devises compatibility problems arose. There were vast amounts of hardware and software standards, sometimes one for each vendor. Even different versions of the same application were sometimes incompatible. These compatibility problems were slowly overcome by standardising hardware and software, see for instance Adler

(1995) and Hosaka *et al.* (1981). On the data level heterogeneity problems regarding syntax, semantics and pragmatics occurred. Syntax heterogeneity deals with the structure of the information, semantic heterogeneity with the content of the information and pragmatic heterogeneity with how the information is handled, e.g. concurrency control, Toussaint *et al.* (2001). The data heterogeneity problems were overcome for instance by using relational databases as data repositories, Hoffer *et al.* (2005). In the early coordination phase when middleware was used, only predefined data and information could be interchanged. With incorporated IT systems and central databases, data and information were accessible for everyone using the IT system, Dahlbom (1997) and Kelly *et al.* (1997).

Integration: one company-wide solution

In the last part of the 1990s total business solutions emerge. These solutions integrate databases and functionality as well as providing a common user interface. In industries enterprise resource planning (ERP) systems and industrial automation such as computer integrated manufacturing (CIM) and supervisory control and data acquisition (SCADA) systems had and still have a central role of bringing total integration, Gordon (2000) and Nikolopoulos *et al.* (2003). CIM and ERP systems integrate "everything", CIM in a production control level and ERP on the company administrative level. Until recently, these systems have been separated, but in the field the trend is now moving towards integration of these technical systems and administrative systems, see for example Dahlfors and Pilling (1995) and Bratthall *et al.* (2002).

The development of computerised maintenance management support

Based on the literature survey described in the following, the author would like to present a historical review of the development of maintenance information technology from the 1960s and until today, as it is presented in scientific literature.

Survey design

A literature survey covering maintenance information technology was conducted in autumn 2003/Spring 2004. The databases used for the survey were Elsevier, Emerald, and IEEE. Following combinations of keywords were used; decision support system, expert system, computerised and information system combined with maintenance, asset management or maintenance management system. An additional search was made in a full text database search tool (ELIN) that integrates a vast number of databases, e.g. Elsevier, Emerald, IEEE, Proquest and Springer, using the same keywords as mentioned previously, i.e. decision support system, expert system, computerised and information system combined with maintenance, asset management or maintenance management system. A total of 97 articles within the relevant topic were found in this survey. All articles were published in the period 1988 to 2003. Additional reading was made in books about maintenance and computerised maintenance management systems, especially to capture the missing period 1960-1988. The number of articles per year is presented in Table I. The historical description is divided into three periods, 1960-1992, 1993-1998 and 1999-2003. The amount of articles from each period is found in Table I. The periods are representing different stages of maintenance information technology maturity and are consistent with the three phases of corporate IT development: Introduction, Coordination and Integration.

Year	Number of articles	Period	Number of articles
1988	2	1988-1992	21
1989	5		
1990	5		
1991	5	1993-1998	40
1992	4		
1993	7		
1994	5		
1995	7		
1996	9		
1997	6		
1998	6		
1999	4	1999-2003	36
2000	6		
2001	9		
2002	6		
2003	11		
Total	97		97

Table I.
Number of articles per year

Introduction: the emergence of maintenance information technology

According to Wilder and Cannon (1993) computerised maintenance support was not existent before the year 1960. There were maintenance planning systems available for mainframes in the 1970s, where the computation time was shared with other departments giving high priority for the most important processing, Kelly (1984). Maintenance was most likely not one of the high priority activities and Kelly concludes that the tasks were limited to some scheduling of preventive actions. The first maintenance IT automation step was available for the large companies and supported preventive maintenance, though in a low extent, while other companies had to rely on manual maintenance management.

In the beginning of the 1980s minicomputers with dedicated programs were developed giving higher freedom for the maintenance department to systematise, plan and check up maintenance activities, Wilder and Cannon (1993) and Kelly (1984). In 1985, at least 60 CMMS were available, Raouf *et al.* (1993). At this time, the backbone of CMMS was established, consisting of functionality for scheduling, plant inventory, stock control, cost and budgeting and maintenance history, Wilson (1984). Another popular kind of IT support was expert systems (ES) for reducing downtime when conducting reactive maintenance. About half of the papers written during the period 1988-1990 are within ES for fault detection and troubleshooting, see for example Walters (1990), Donaghy and Omanson (1989) and Ho *et al.* (1988).

Technological innovation is also discussed in the late 1980s. One project conducted by US Navy aimed at digitalising and integrating several sources of maintenance information, using ultra modern techniques such at optic disc storage, Landers *et al.* (1989). Furthermore, US Air force demonstrated the first hand-held computer that could integrate on-the-place failure data with historical data and manuals in order to reach failure diagnosis, Link (1989).

The state-of-the-art in computerised maintenance management systems of the late 1980s is given by Mullin (1989), who describes the computer aided maintenance

management systems at Ford as developed independently, poorly integrated and with poor interfaces.

Coordination: structuring the maintenance IT resources

About a third of the papers studied from the first part of the 1990s deal with the concept of CMMS and words like efficiency and cost reduction occurs. Ben-Bassat *et al.* (1993) present an expert system for cost-effective utilisation of maintenance resources. The ability to identify and follow up maintenance costs using CMMS' is discussed in Gehl (1993). Jones (1994) concludes that if a CMMS will be cost-efficient, its introduction and use must be connected to organisation culture and the maintenance as well as business strategy. The aspect of easy used interfaces such as in Hall *et al.* (1994), where graphics are used to reach user friendliness, is also pointed out. The word integration shows up for the first time now. Fung (1993) promotes the use of CMMS to integrate maintenance with, e.g. quality assurance and energy management. Nolasco (1994) discusses CMMS and integration between maintenance, purchase and accounting and Sherwin and Jonsson (1995) promotes the use of management information systems to integrate maintenance and production. MMIT is thus apprehended as a useful resource; the work of connecting different maintenance application begins, as well as the connection between maintenance and other working areas is explored.

The main focus of the 1990s lies in how to manage preventive maintenance though, for instance in the shape of expert systems for policy planning, scheduling and fault diagnosis, see, e.g. Batanov *et al.* (1993), or IT systems for preventive maintenance management, Fung (1993), Gehl (1993) and Raouf *et al.* (1993). At this time, there are more than 200 commercial CMMS packages available in North America alone, Campbell (1995). The military is still in the front-end of maintenance, for instance with two projects aimed at computerised life cycle cost (LCC) analysis of weapon systems, including preventive maintenance considerations, Hansen *et al.* (1992) and Awtry *et al.* (1991). LCC simulation is also the topic of Ostebo (1993). Expert systems are still a common topic in this period, see, for instance Gung-Huei *et al.* (1994), Batanov *et al.* (1993) and Mitchell (1991).

Also, papers discussing computer support for predictive maintenance appear. Sato *et al.* (1992) and Itaka *et al.* (1991) describe an advanced system for condition monitoring and maintenance communication for power transport lines. Wichers (1996) discusses a reliability-centred maintenance based system for maintenance planning, specially stressing condition monitoring, which is connected to a manual or computerised maintenance management system. Pearce and Hall (1994) recognise the advantages of vibration monitoring and the importance of connecting on-line monitoring data to a computerised maintenance management system. We can see that computerised support for condition monitoring is developed but not widely incorporated into the administrative IT systems.

Integration: maintenance and maintenance IT as a part of the whole company

In the end of the 1990s, the economic aspect appears even stronger. Maintenance IT is discussed with respect to cost-effectiveness and cost reduction, see for example Gendreu and Soriano (1998), Labib (1998) and Weil (1998). Jonsson (2000) connects IT maturity in maintenance with profitability. The term integration is used to

discuss integrated CMMS solutions during this period, where, e.g. integration of CMMS and asset management systems is discussed, Boyles (1999) and Weil (1998), as well as the benefits of integrated CMMS are addressed, Panucci (2000). Zhang *et al.* (1997) discusses the use of artificial intelligence to achieve an integrated maintenance management system that takes into consideration not only equipment condition, but also production quality, efficiency and costs. The development of computerised communication methods, such as remote monitoring, telemaintenance and geographical information systems, also affects the topics of papers; see, for example, Hadzilacos *et al.* (2000), Bingel and Halsch (1996) and Laugier *et al.* (1996).

The topic of decision support systems has increased continuously during the studied years. In the period of 2001-2003 decision support systems is discussed in eight of 26 papers, i.e. about one third of the papers (to compare with period 1988-1990 when the figure was two out of 12 papers). Yam *et al.* (2001) for instance discusses operational and maintenance cost reduction as the result of a more accurate condition-based fault prediction and diagnosis reached by decision support systems. Other examples of IT support for diagnosis and prognosis are found in Yagi *et al.* (2003). Noticeable is also that papers about expert systems have decreased from about 40 per cent (five of 12 papers) in 1988-1990 to about 20 per cent (five of 26 papers) in 2001-2003.

The development of computerised maintenance management compared with other computerised management applications

The development of maintenance IT has followed the general development of IT applied in industries, from automation through coordination to integration. A slight slack can be distinguished though for maintenance IT compared to other corporate IT. This can be seen in the development of maintenance management IT compared to other management applications. Systems that support automation of manual administrative routines, e g. order handling, general ledger and payroll systems have been stressed when introducing IT into the enterprise, see, e.g. Persson *et al.* (1981) and Nolan (1979). When IT applications dedicated for finance were commonly in use during the seventies and eighties, maintenance management IT systems were not as common, Wilson (1984). Still we can find maintenance departments relying on manual systems, or where IT support is combined with paper documents and where a low extend of history is kept. In a survey of maintenance management in Swedish industry, where 118 companies were included, 22 per cent of the companies answered that they use manual maintenance management systems and 35 per cent a combination of manual and computerised maintenance management system, while 36 per cent use computerised support, Alsyouf (2004).

While other areas of the business were integrated into enterprise wide systems, such as enterprise resource planning (ERP) systems and computer integrated manufacturing (CIM) systems, maintenance has not been well represented. CIM and ERP systems were de facto in use during the late 1990s and early 2000s, but most of these systems did not include maintenance modules, Nikolopoulos *et al.* (2003). Al-Najjar (1996) points out that everything is included in computer integrated manufacturing but maintenance.

Results and conclusions

The survey of computerised maintenance support reveals that the focus of MMIT has changed in four aspects during the 40 years that has been investigated:

(1) From technology to use.

(2) From maintenance function to business integration.

(3) From reactive maintenance to proactive maintenance.

(4) From operative to strategic maintenance considerations.

These shifts in focus are further discussed in the following.

Technology – use

In the microcomputer era automation of routines was in focus. Main benefits of maintenance IT lay in reducing manual paper work and getting a grip of maintenance specific resources. IT in enterprises was a new phenomenon and the technology itself was stressed in the early papers. As the IT maturity of enterprises grew, the technological construct of maintenance IT was discussed less often. Instead, the focus shifted to the use of IT. MMIT is in the later papers treated as a tool, which can benefit the user if used properly, and the actual benefits are stressed.

Maintenance function – business integration

While the literature in the early years is considering the maintenance function and its information technology needs, an increased use of the integration concept is seen in later papers. By the use of, and by integrating, CMMS advantages in maintenance could be achieved.

Reactive maintenance – predictive-proactive maintenance

A trend of increasing IT support for maintenance management activities appears in the description, from mainly supporting technical reactive and preventive maintenance strategies in the microcomputer era to predictive condition-based strategies when different corporate IT resources could be integrated. Today, as predictive-proactive maintenance strategies, which help in avoiding damage initiation by detecting the damage causes, are strongly gaining ground we should be able to see this reflected in contemporary research. The growth in amount of papers published the last years discussing integration and DSS for maintenance could be a tendency of this. Furthermore, the discussion about financial benefits of maintenance and the connection between maintenance and production performance together with IT would imply a more holistic view of the maintenance role in companies. Having a holistic perspective on maintenance enables predictive-proactive maintenance.

Operative maintenance considerations – strategic maintenance considerations

A shift in focus from operative maintenance concerns to strategic maintenance concerns could be seen in the study. Notable is, e.g. the increased number of papers in the later years dealing with economic advantages that could be reached by using CMMS, whereas the focus in the early years were in describing how the operative maintenance work could be speeded up and automated by using computers.

Practical implications

The main aim of his paper was to fill a gap recognised in the area of MMIT, which would benefit researchers working in maintenance management and industrial information systems science. This paper could serve as a basis for further research on the topic. But a description of the development of MMIT is not only beneficial for researchers. Knowing the advancement of MMIT adds to the understanding of today's computer applications for maintenance management, which is crucial for every maintenance manager using or purchasing MMIT. Notable is that MMIT has followed the development of corporate IT in general. MMIT is in other words built on the same structures as other IT applications. Moreover, maintenance management applications have suffered from a slight slack compared to corporate IT systems in general. This could be used as a means to identify the future trends of MMIT, as well as possibilities and problems with the new technology, tools, techniques and methods. In that way we can make use of the findings from other areas in the smooth development of future IT applications for maintenance.

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