A knowledge-based system for supporting performance measurement of AMT projects: a research agenda

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Abstract *This paper discusses the potential of applying knowledge-based systems (KBS) in supporting performance management of advanced manufacturing technologies (AMT) and suggests a viable research direction. It describes a research framework using factor analysis to identify factors relevant to measuring performance of AMT. The framework can be used as a first step in developing a KBS for performance measurement of AMT projects. We believe that a well-developed KBS is a powerful and versatile tool for conducting and controlling performance measurement of AMT projects in a manufacturing organization.*

1. Introduction

It is well known that investment in information technology (IT) and information systems (IS) is huge and keeps on rising in organizations in both the service and manufacturing sectors. Investment in advanced technologies (e.g. computer-aided design (CAD)/computer-aided manufacturing (CAM), flexible manufacturing systems (FMS), manufacturing resource planning (MRPII), robotics) in the manufacturing sector seems heavier compared with the service sector. There is no doubt that investment in advanced technologies is big business, particularly in a manufacturing environment. However, as Strassman (1990) has pointed out, the size of IT spending bears no relation to subsequent IT effectiveness. Basically, industry practitioners apply computer technology in two basic ways: as physical systems and as IS. CAD/CAM and robotics are examples of application of computer technology as part of a physical production system, while a manufacturing information system is an application of IT in production providing information in support of production and operations management.

Performance measurement systems for investment in advanced manufacturing technologies (AMT) such as CAD/CAM, FMS, MRPII, robotics, etc. are an under-developed and under-managed area which organizations cannot afford to neglect. Most companies have difficulties with performance measurement of their AMT projects due to a lack of systematic frameworks and tools, yet the significance of performance measurements and their role in competitive manufacturing cannot be over-emphasized. We believe that

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organizations need to be made aware of the context in which effective performance measurement of AMT projects can be conducted. A well-developed knowledge-based system (KBS) would be a solution to this problem, as it is a powerful and versatile tool for conducting and controlling performance measurement of AMT projects in a manufacturing organization.

This paper is organized as follows. In Section 2, we present a review of the literature on performance measurement for IT/IS/AMT investment in manufacturing and applications of KBS in production and operations management (POM), particularly on performance measurement. Section 3 outlines the development framework of a KBS which will be constructed following a six-stage methodology for the development of KBS. Section 4 gives implications of the study and Section 5 concludes the paper.

2. Literature review

Performance measurement for IT/IS/AMT investment in manufacturing

A number of research projects have been conducted on performance measurement relating to AMT. Kakati and Dhar (1991) argue that the results of FMSs can be truly startling, but that when it comes to traditional financial evaluation their results are disappointing. They maintain that this is due to the inability of such financial appraisal methods to incorporate most of the strategic benefits of FMSs in their analysis. Bromwich and Bimimani (1991) state that a good approach to the appraisal of AMT is to evaluate the strategic benefits informally while including a quantitative analysis. Samuels *et al.* (1990) propose a three-stage model for the evaluation of proposals for AMT projects. Airey and Young (1983) argue that conventional financial appraisal techniques are ill-suited to capital investments like AMT projects. Azzone and Bertele (1989) provide for the linking together of economic measures and strategic objectives in their FMS evaluation model. Udoka and Nazemetz (1990) propose a methodology for segregating successful and unsuccessful CIM projects, based upon each project's performance relative to the goals set for the project.

Dos Santos *et al.* (1993) point out that determining whether IT investments can increase a firm's value poses many problems that are widely discussed in the information system literature (Strassmann, 1990; DeLone and McLean, 1992). Due to these problems, very few studies have attempted to link IT investments to firm performance (Dos Santos *et al.*, 1993). Traditionally, IT investment decisions have been based on cost/benefit analysis and qualitative assessments of payoffs, but the most common investment measurement approaches have not helped assign a value to the investment and manage against that value (*I/S Analyzer*, 1992). However, it has been suggested that the value of IT investments can be inferred from user satisfaction, system usage, system quality, information quality or impact on individual users (DeLone and McLean, 1992), or from the direct impact of the IT application on the performance of activities affected by it (Kekre and Mukhopadhyay, 1992; Banker and Kauffman, 1988).

Performance measurement research has focused on measurement problems attributable to traditional cost accounting systems in manufacturing firms adopting world-class manufacturing techniques. Kaplan (1983) highlights these shortcomings of traditional cost accounting in today's dynamic manufacturing environment. Plossl (1990) states that advances in the technology of manufacturing planning, control, and operation have made conventional cost accounting practices not only obsolete, but also dangerous.

As performance measurement research progresses, researchers have begun to explore the relationship between functional and business unit performance (Lockamy and Cox, 1995). AMTs require large investments. Over the past two decades, the traditional investment appraisal criteria and techniques used in the evaluation of AMTs have come under increasing scrutiny (Lefley and Sarkis, 1997). No framework has been accepted for providing standardized value assessments across firms (*I/S Analyzer*, 1992).

Bacon (1992) examines the criteria used by 80 organizations in allocating strategic AMT resources. Senior executives were asked to indicate which of 15 criteria they used in deciding among competing projects. The results indicate that criteria such as support of explicit business objectives and response to competitive systems are most important in selecting AMT investments. Although financial criteria are used by most organizations, the extent of analysis and application appears to leave ample room for improvement.

Lefley and Sarkis (1997) conduct an empirical study and point out that sophisticated investment appraisal techniques, such as discounted cash flow, are perceived to be unsuitable for the evaluation of AMT projects, and what is preferred by management is a basic financial appraisal method, such as payback, possibly linked to some form of qualitative evaluation.

Applications of artificial intelligence and expert systems in production operations management (POM)

Growth in the number of expert systems applications is particularly prominent in engineering and manufacturing (Spur and Specht, 1992). There are many areas in the engineering and manufacturing industries where expert systems in POM have been applied. Some examples of application of ESs in POM are capacity planning (Stroebel *et al.,* 1986), design (Theodoracatos and Ahmed, 1994; Ngai and Chow, 1999), facility layout (Lesknowsky *et al.,* 1987), process control (Dagli and Stacey, 1988), process planning (Wang and Wysk, 1987), purchasing (Cook, 1992), quality control/quality management (Tolar and Platt, 1992), and scheduling (Kusiak and Mingyuan, 1988; Kodali, 1994).

Cheng and Bizruchak (1991), Eom (1992) and Jayaraman and Srivastava (1996) have provided comprehensive reviews on expert system applications in the POM area. Some more recent and good examples are use of AI in manufacturing (Buckley and Murthy, 1997) and industrial applications of KBS/ES (Batanov, 1998).

Although POM is a promising area for ES, applications of ES to support performance measurement of IT/IS/AMT projects have to date been minimal.

Bowen and Paying (1987) describe an expert system prototype which analyses performance indicators. These are key statistics describing levels of achievement in terms of both policy objectives and efficiency. Fisher and Nof (1987) propose a KBS to aid analysis in the appraisal of manufacturing facilities. Cil and Evren (1998) suggest a framework for the acquisition of new manufacturing technology that links manufacturing strategy, market requirements, and manufacturing attributes using an expert system approach. The proposal model is integrated by an expert system approach that includes strategic factors of both a tangible and an intangible nature and is implemented by using the VP Expert shell. To the best of our knowledge, based on an ABI/INFORM search from 1971 to 1998, ESs have not been applied to support performance measurement of AMT projects.

3. Research methodology

The purpose of this paper is to design and develop a KBS to assist managers in identifying performance measurement factors and conducting the corresponding performance measurement of AMT projects in a manufacturing environment. Specifically, we seek to develop a framework for measuring the performance of AMT projects in a manufacturing environment; and design and develop a KBS for supporting the measurement of their performance. The factors captured in the KBS will cover financial, non-financial, tangible and intangible performance indicators.

Although several authors such as Hayes-Roth *et al.* (1983), Hilal and Soltan (1993), Krishnamoorthy and Rajeev (1991) and Turban and Aronson (1998) have provided guidelines for the development process and the main elements of KBSs, the literature contains no specific guidelines for the development process of a KBS for performance measurement of AMT projects. In this study, a development methodology of the system is presented. The research framework for this study will follow the well-established methodology for the development of KBSs, comprising the following steps: identification, conceptualization, formalization, implementation, and testing and validation (Hayes-Roth *et al.*, 1983; Krishnamoorthy and Rajeev, 1991), with some enhancement. The enhanced framework is shown in Figure 1. Essentially, this project will proceed in five stages. The following research issues are addressed in each phase of the framework.

Research issues

Stage 1: data collection:

(1) *Literature review*. Any research problem should show its derivation from the background of existing knowledge or previous research results. Relevant literature relating to performance measurement, AMT project evaluation, and state-of-the-art KBS technology will be studied. This phase also involves the compilation of a list of major relevant factors which need to be considered for a comprehensive exercise on performance measurement of AMT projects.

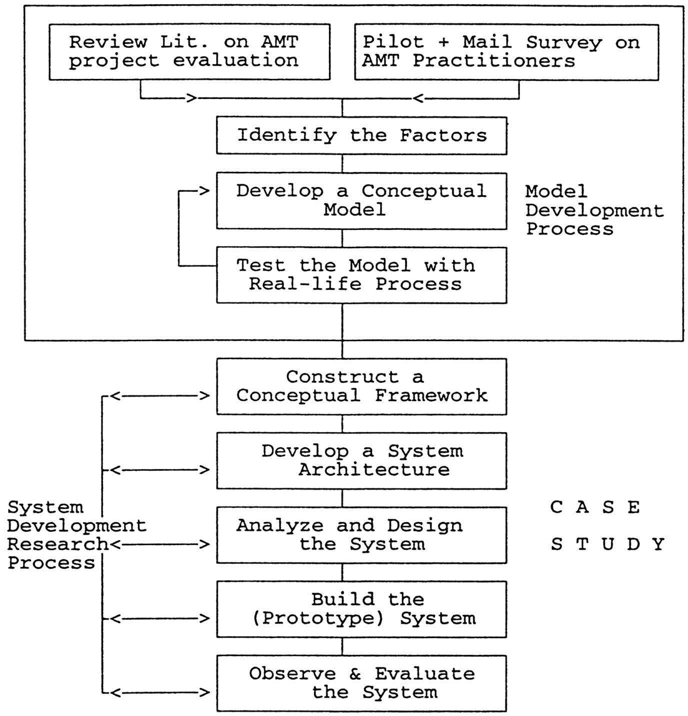

Figure 1.
Research framework

(2) *Pilot and mail surveys*. For the pilot survey, in-depth interviews will be conducted with AMT project managers and IT consultants concerning the factors identified in (1). The mail survey will provide "snapshots" of AMT performance measurement practices and usage of relevant measurement tools in Hong Kong and the Chinese mainland. The survey results will also help validate the relevant factors identified in the literature review.

Stage 2: identification of the factors. As a result of stage (1) and (2), a list of factors will be identified from reviewing the literature, the pilot survey and the mail survey.

Stage 3: formulation of the conceptual model. The conceptual model will be constructed based on the literature review and survey results. The proposed model will suggest several criteria for measuring performance, including financial, non-financial, tangible and intangible performance indicators, such as return on investment (ROI), discounted cash flow/internal rate of return (DCF/IRR), net present value (NPV), profitability index (PI), payback period, customer service, flexibility, competitiveness, customer satisfaction, product quality, internal/external communications and management information, competitive advantage and customer-supplier relationship. A "factor analysis" on the identified factors will be performed in order to establish the major dimensions along which the performance of an AMT project will be analyzed and evaluated. The model could function as a foundation for comparing value measurements across industries.

Stage 4: testing of the conceptual model with real-life projects. The proposed conceptual model will be empirically tested by using selected real-life projects from the manufacturing industry. The validity of the model can be established through in-depth case studies. Once the conceptual model is developed, it can be captured by the KBS.

Stage 5: development of a KBS:

(1) *Identification.* Identification refers to the process of characterizing key problem aspects (McGraw and Harbison-Briggs, 1989). During this stage, the researchers will become familiar with the domain and select appropriate, available domain experts and other source materials.

(2) *Conceptualization.* Conceptualization involves linking the key relationships between the primary concepts and expert conclusions with the knowledge domain as well as other information sources, while knowledge acquisition involves the acquisition of knowledge from domain experts, books, documents or computer files (Turban and Aronson, 1998).

(3) *Formalization.* Formalization requires the knowledge engineer to "map" the recognized concepts, sub-tasks, relations and other information into formal representation mechanisms (McGraw and Harbison-Briggs, 1989). In this stage, the knowledge base will be organized and structured. We will use both frame-based and rule-based methods as knowledge representation for the system.

(4) *Implementation.* The system will be developed on a personal computer platform using an expert system shell that runs on Microsoft Windows™. The prototype will be tested for its performance during development, as well as after completion, for accuracy and completeness. By building a prototype, the various issues which arise can be addressed. For instance, new concepts of user interface design can be evaluated. Prototypes and the prototype building process can be used to clear up a variety of problems, and to learn about the concepts, framework and design.

(5) *Testing and evaluation of the system.* Once the system is built, testing and evaluation can be performed. Potential users and experts will be invited to help with evaluation of the system. Diskettes containing the prototype system and evaluation forms will be sent to AMT practitioners in Hong Kong and the Chinese mainland, i.e. potential users who have responded to the survey in Stage 1. Further, the use of the prototype system can be observed through case studies.

The choice of this approach to KBS development is based on our prior experience and lessons learnt from the development of several KBSs and a management support system EXSGACM (Tsang and Ngai, 1996), MSS4TQM (Ngai and Cheng, 1999), ICADS (Ngai and Chow, 1999), and EXSICE (Ngai and Li, 1998). It is easy to apply and will provide valuable guidance for developing the proposed system.

4. Implications of this study

This paper describes a research framework using a "factor analysis" to identify factors which will be captured in order to establish the major dimensions along which the performance of an AMT project will be analyzed, evaluated, and used as a first step in developing a KBS for performance measurement. Not only will this allow the identification of indicators of performance measurement, but the approach also gives insights into how the KBS can be used to support AMT projects. This study has several implications for performance measurement research.

Awareness of KBSs in performance measurements of AMT projects

This paper has introduced the reader to the potential use of KBSs to support performance measurements of AMT projects in an organization, and will hopefully increase the awareness of industry professionals of the benefits of applying KBSs to support performance measurement of AMTs.

Hypothesis formulation and testing

One of the uses of the framework is to generate relevant testable hypotheses for researching the use of KBSs in supporting performance measurement, as demonstrated by the example below. The formulation of testable hypotheses is important, since the hypotheses determine the potential significance of a research effort. We believe that a research framework such as this is a basis from which the value of the KBS approach to support performance measurement can be objectively and rigorously tested. As for future research, we plan to conduct a field study on the following research question and its corresponding hypotheses: Can a KBS help and improve in performance measurement of AMT projects?

- *H0*: There is no significant difference between using and not using a KBS in the outcomes of measuring performance of AMT projects.
- *H1*: There is a significant difference between using and not using a KBS in the outcomes of measuring performance of AMT projects.

Develop a research framework for ESs supporting performance measurement for IT/IS/AMT projects

Performance measurement systems may be difficult to develop and generalize. A large-scale empirical study is needed to survey a variety of organizations to determine a model for measuring performance of AMT projects. The application of ESs for performance measurement of AMT projects is relatively unexplored and may be a fruitful topic for further research. For instance, would the proposed KBS for performance measurement be a standalone system or a distributed system? The research agenda suggested in this paper will, in our view, provide practical guidance for developing KBSs to support performance measurement of AMT projects.

5. Conclusions

We believe that investing in advanced technologies in manufacturing without performance measurement is like hunting ducks at midnight without a moon in the sense that it is likely to result in squawking and damage. There exist no systematic framework and a set of tools for supporting performance measurement of AMT projects. The proposed tool will provide AMT managers with a useful range of information on performance factors, which will enable them to monitor the identified performance indicators. It will help in measuring AMT payoffs and substantially reduce cost and time delays in providing accurate assessments. The anticipated benefits of using the system include:

- managers will be able to use the KBS as a dynamic checklist on any combination of performance factors;
- managers will be informed of performance indicators related to all identified performance measurements;
- the KBS will provide a systematic and effective way of transferring expertise into the knowledge base; and
- it will serve as a training tool for inexperienced AMT managers.

The research proposal we put forward here works on the basis that KBS possesses wide potential applicability in decision making in respect of measuring performance. We believe that other industries can apply a similar approach to develop KBSs to support performance measurement of their investment projects. Finally, we hope that this paper will stimulate and promote the use of KBSs among manufacturing professionals.

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