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Research Article

Integrating Information Technologies and Knowledge-based Systems: A Theoretical Approach in Action for Enhancements in Production and Inventory Control

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The heightened focus of global competition has increased the necessity of manufacturing in combination with information technologies to continuously improve production flexibility and product quality, delivery and cost. Coupled with uncertainty and delays in information transmission lags, this increased focus has also created confusion and difficulties in production and inventory control management. Many manufacturers have abandoned the simple make-to-stock environments in favor of more complex make-to-order, configure-to-order, and engineer-to-order. At the heart of this range of options is the information technology (IT) that makes it all possible. Of the most popular new technologies for supporting production and inventory control (PIC) are solver technologies, intelligent decision support systems, and knowledge-based systems. This paper discusses the integration of IT and knowledge management (KM) and the future trends in KM that are likely to impact PIC. Copyright © 2002 John Wiley & Sons, Ltd.

'We are drowning in information but starved for knowledge'—John Nasbitt, *Megatrends*

'The most important contribution management needs to make in the 21st century is to increase the productivity of knowledge work and the knowledge worker.'—Peter F. Drucker

INTRODUCTION

The search for improvements in production and inventory control have attracted increased attention from gurus and researchers who try to popularize and explain success stories. Research has provided a rich body of knowledge specific to production and operations management. Santhanam and Elam (1998) examined 430 articles related to knowledge-based systems (KBS) which were published between 1980 and 1995. The importance of knowledge and how it supports business problem solving is the basis for the study and development of KBS. KM and PIC have been examined as separate spheres of managerial thought in the literature. However, this separation is really a division that artificially limits both the business application and managerial impact of both schools of thought. As we move into the beginning of the twenty-first century, it is becoming increasingly obvious that there is an intersection of these two schools of managerial thought with the potential for each to expand and add value to the other. Analysis of the academic literature reveals arguments that propose integration of manufacturing systems for production and inventory control. One of the most important issues is the basic problem of shop scheduling to satisfy a target performance measure.

Belz and Mertens (1996) discuss how experts systems or knowledge-based systems could serve

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as intelligent front-ends to interface between computer-based simulations and the user. Their studies include a decision support system (DSS) for short-term scheduling in manufacturing which when coupled with expert systems and simulation can assist the production manager in handling production disturbances. They concluded that knowledge-based systems can increase the application range between simulation and the user.

Pflughoeft *et al.* (1996) describe an architecture of an intelligent knowledge-base simulator (KBSim) that provides a systematic research capability for flexible manufacturing systems (FMS). The KBSim is applied to a FMS scheduling problem to reduce mean flow time and tardiness. When compared to the more common scheduling heuristics, KBSim proved to be a more useful tool in the automation of adaptive system control and facilitating 'good' solutions for the decision-maker.

Kant and Sridharan (1998) investigated scheduling information in a materials requirement planning (MRP) system used to help inventory performance. Their research objectives looked at the need for a possible redirection for the design of manufacturing systems, more specifically, a redirection that will exploit the capabilities of modern computer technologies. Their results concluded that improvements could be accomplished but would be influenced by the operating environment. Although a 'patch' for MRP systems was proposed, their conclusion was that 'the next step would be to expand the scope of these systems so that they can supplant current MRP-based technology by providing a tightly integrated method combining raw material planning with production scheduling and control' (p. 496).

Dubois and Koning (1994) began their discussion by stating that 'pieces of knowledge used in Artificial Intelligence (AI) systems are not always dedicated to inference purposes' (p. 337). This is true since there is a certain amount of human expertise often missing and required to integrate into the decision-making process. Their studies, applied to job-shop scheduling, suggest a mechanism to handle heuristic knowledge-based system using social choice theory.

Parker (1998) points out that advanced planning is achieved by 'solver' technologies such as heuristics and mathematical optimization techniques, and states that simulations are not solver technologies, but a way to evaluate a set of solutions. While it is clear that scheduling systems have evolved from local stand-alone tools into a more shared environment such as Enterprise Resource Planning (ERP) systems, dynamic planning still deals with short planning horizons. It typically takes into account the most current shopfloor conditions specific to a few days' worth of production. The significance was pointed out in an earlier discussion (Parker, 1996). The dynamics of production scheduling is more complicated than the game of chess. Even though the game of chess is clearly defined (with the number of possible moves having been calculated at 10 to the 120th power) in manufacturing, 'perfect' knowledge is not possible.

Most experts will agree that regardless of the level of technological tools—manufacturing resource planning (MRP-II), materials requirement planning (MRP), just-in-time (JIT), Total Quality Management (TQM), and Enterprise Resource Planning (ERP)—the integration of information technologies such as knowledge-based systems, intelligent decision-support systems, and solver technologies is a key to supporting/improving PIC.

A BRIEF BACKGROUND ON PRODUCTION AND INVENTORY CONTROL

Production and inventory control (PIC) is a function of managing priorities and capacity measured by three primary objectives: maximizing customer service, minimizing inventory investment, and maximizing operating efficiency. Priorities entail much more than determining which jobs are the hottest—it means knowing the plan and what jobs are needed and by when to support the plan, and then keeping this information up to date. Capacity is the ability to keep up with the priorities by knowing how many man-hours and/or machine-hours are needed to meet the planned priorities.

In practice, the problem of priority and capacity planning in a PIC system is to release work-orders to the shopfloor and impose due dates in order to meet the committed dates given to the customer. This formal production control system, such as materials requirement planning (MRP), just-in-time (JIT), or theory of constraint (TOC), is the process of assigning processed products and personnel resources to an operation according to known constraints in order to satisfy a target performance measure. However, these dates usually will not be meaningful to the shopfloor for very long because even if the forecasts were perfect, customers do change their schedules, and hence the priorities change. Moreover, out on the shopfloor, an informal system exists where the shopfloor supervisors and expeditors are trying to get the processed parts through that are 'really needed' as a result of the 'knee-jerk' reactions caused by the changes in the customer requirements. In a typical manufacturing company, the informal and the formal system tend to develop into one chaotic and confused system (often referred to as 'our system'). The reality is that there is a formal system that simply does not work properly, and an informal system that attempts to correct for it. Looking around the typical shopfloor, and one will find many work-orders that are late and not being expedited, and the system consists of 'hot lists' and 'shortage lists' of work-orders that are really needed, while juggling resource capacities. It is often poor and confusing, and due to its dynamic characteristics, does not make it possible for the shopfloor to deliver a successful execution of the schedule, thus leading to less than ideal performance.

The reality is that PIC problems are dynamic. The decisions about priorities and capacities to meet the objectives depend on the situation at the time of the decision. The decisions due to its dynamic characteristics are complex and needs to be adaptive to its ever-changing environment. Hence the basic problem of PIC is to automate more of the decision-making processes.

INTEGRATION OF TECHNOLOGIES

The decisions involving production and inventory control are based on many interdependent factors. These factors include (but are not limited to) work-order information, process information, shop load-balancing information, actual progress information, and shopfloor personnel information. In shop scheduling, the most commonly used method is materials requirements planning (MRP). The decision-maker then works through a set of processes to reduce the number of possible alternatives in order to determine a plan or schedule. The enigma associated with that decision is that it was made based on a set of 'prior' knowledge at a particular 'past' discrete moment in time. Hence, the dynamics of PIC is that when a plan reaches the implementation stage, it has (or is subject to) change—creating another set of possible alternatives. Therefore, the decision-maker, being faced with many options and little time to react, must take advantage of the possible new technologies for supporting PIC. Of the most popular new technologies are solver technologies, intelligent decision-support systems, and knowledge-based systems.

Solver technologies such as heuristics and mathematical optimization problems have been the primary tool for decision-makers. But in the more recent decade, there has been a virtual explosion of user-friendly decision support systems (DSS) software for microcomputers—a large number being programs that a decision-maker can use to solve constraint-based business problems. The issue is that the definition of optimal solution may not be a practical business solution. Other software packages apply dynamic scheduling and advanced planning through the use of discrete-simulation-based systems. However, a discrete-simulation-based system does not usually provide a solution; rather it allows the decision-maker an opportunity to examine possible consequences of alternatives. Therefore the speed of the decision-making process is perhaps more important than obtaining an optimal solution. This makes the evaluation of all possible solutions broad and rather difficult. Therefore intelligent decision support systems (Figure 1) argue for a simulator that can provide support for the decision-making process. The generalized concept is that an intelligent simulator includes a problem-oriented interface. This interface allows the decision-maker to define the goals and parameter of decision context. The simulator interacting with its environment will then design the appropriate what-if experiments, execute a series of simulation runs, record the results, and then perform an analysis of the results. The decision-maker is then left with the analysis of the results to make the final decision (Pflughoeft *et al.*, 1996).

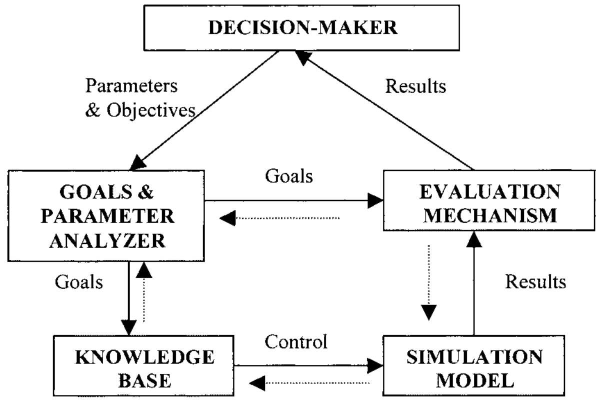

Figure 1 KBS model

Once the decision-maker has selected the parameters and objectives, the goals and parameters are analyzed by the system. The transformation of the parameters and objectives into measurable goals is then used by the knowledge base in order to determine control strategies. The knowledge base would then conduct the controlled experiments in the simulation model. The results are then fed into the evaluation mechanism. The evaluation mechanism would then assess the results, comparing to the goals and parameters that had been determined by the decision-maker. The decision-maker would then evaluate results and determine the appropriate action.

Due to the various disruptions throughout the plan, the dotted line depicted in Figure 1 represents a feedback mechanism. The representation of knowledge is a combination of data structures and descriptive rules, which would lead to a desired knowledgeable behavior. Since there are many instances from where knowledge is learnt, this would then be an iterating process, where the learned behavior is updated to the knowledge base system for future transformations. This would further the assistance and support given to the decision-maker. However, there is usually more than one solution for a set of constraints, which Dubois and Koning (1994) added that 'human expertise is required to integrate the sub-problems, provide the missing pieces, and guide the search process for making decisions' (p. 338).

TRANSITIONING TO A KNOWLEDGE MANAGEMENT SYSTEM

To remain competitive and profitable in today's dynamic e-business environment, organizations are trying to capture, configure, and manage content and business know-how for corporate advantage. Without the ability to coordinate people, content and processes, provided by a knowledge management (KM) strategy, organizations are ill-equipped to harness the Internet and realize competitive advantage. Knowledge is simply stated as information combined with experience, context, interpretation, and reflection (Davenport *et al.*, 1998). KM is a holistic process that helps organizations find, select, organize, evaluate, integrate, disseminate, use and transfer important information and expertise from both internal and external sources necessary for activities such as problem solving, dynamic learning, strategic planning and decision-making. Over the past couple of years, a distinctly new brand of KM has emerged which includes not just the facilitation of knowledge sharing and transfer but also the production of new knowledge, or innovation. This second-generation KM enhances knowledge production, or knowledge making as well. This next generation of KM will see it move from being the somewhat stand-alone initiative and entity to being totally integrated into an organization's business and work processes. Turban *et al.* (2000) state that information overload reduces the decision-making capabilities of knowledge workers by 50%. KMS should aid by collecting and analyzing different types of data (hard and soft) to enhance the user's decision-making process. In the discontinuous environment often faced by PIC executives, the importance of both techno-centric and socio-centric approaches is captured by Malhotra (2000) who states that 'knowledge management caters to the critical issues of organizational adoption, survival, and competence in the face of increasingly discontinuous environmental change. Essentially it embodies, organizational process that seeks synergistic combination of data and information processing capacity of information technologies, and the creative innovative capacity of human beings.'

The knowledge-based perspective postulates that the services rendered by tangible resources depend on how they are combined and applied, which is in turn a function of the firm's know-how (i.e., knowledge) (Alavi and Leidner, 2001; Spender 1996a,b). Advanced information technologies (i.e. Internet, intranets, extranets, groupware, data warehousing, data mining, intelligent software agents and workflow systems) can be used to acquire, capture, organize, transfer and apply knowledge as shown in Figure 2.

Since most manufacturers are under pressure to increase yield, reduce cost (including supply costs), ensure product quality and improve time to resolution of problems on the shopfloor, they seek any leverage that can help them achieve critical velocity to raise performance above a plateau. Unfortunately this has been hard to do with ERP and SCM applications, since they lack analytic capabilities that can give manufacturers and procurement specialists' deep insight into manufacturing processes and supply chains. On the other hand, as a

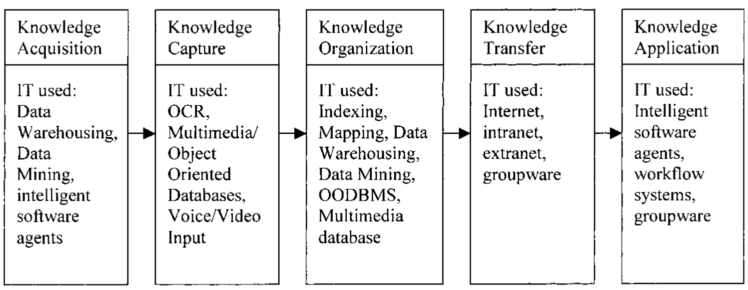

Figure 2 The dimensions of knowledge and the technology used in each dimension

complement to ERP and SCM, supply chain intelligence (SCI) analytic applications enable strategic decision making by operating on highly detailed information collected from the entire supply chain, i.e. from material procurement to the manufacturing floor through every stage of the product's life cycle and into the hands of the end-consumer where warranty periods may apply (Russom, 2000). For example, SCI serves as a broad business intelligence layer with data models and analytic algorithms for each stage of the product life cycle for analyzing historic supply chain and manufacturing performance, shopfloor data, what-if analysis that helps to forecast material and production line needs and parametric test equipment data from the factory or the field.

This can lead to a rise in manufacturing performance by helping manufacturers evaluate the long-term quality and yield ramifications, minimize inventory and/or cash reserves for warranty fulfillment by correlating design/component sourcing decisions with failure rates in the field, and explain production outages caused by quality/compatibility problems with specific materials from specific suppliers.

The traditional view of knowledge management mostly relies on the prepackaged or taken-for-granted interpretation of the knowledge. Such knowledge is generally static and does not encourage the generation of multiple and contradictory viewpoints in a highly dynamic and ever-changing environment. The concept of 'best practices' and 'efficiency optimization' in PIC cannot provide the competitive advantage that companies may be striving for. This is where the concept of knowledge management is not only effective but also essential for an organization's survival. In managing knowledge companies need to be less theoretical and more practical. To get a clear handle on how to manage knowledge in a PIC context, a company must focus on its business processes and the activities that fulfill those processes. When these are known and shared among the responsible decision-makers, then in light of the company's business goals and strategy it will be evident what knowledge is needed to transform these processes either to meet changed goals, or the same goals more effectively. Managing information at the process level is more a demand-pull than a supply-push process. The key is to let those who use knowledge define what they want by way of knowledge. In this context, it should be remembered that knowledge at the process level is cross-functional. For instance, what does a pallet of baked beans in a supermarket mean? To sales it means commission; to marketing, revenue; to finance, an invoice; to the warehouse, shelf space; and to logistics, a size of truck.

LEVERAGING SYNERGIES: INTEGRATING IT AND KM

As competitive pressures increase through consolidation, commoditization, heightened customer expectations, and increased buyer power manufacturers and distributors will have to manage their knowledge initiatives, and to this end e-commerce paradigms and practices are expected to be central enablers. These initiatives will relate to operations and manufacturing concepts such as concurrent engineering, supply chain management, computer-integrated manufacturing, agile and virtual enterprising. Thus, knowledge management initiatives are strategically vital to organizations that wish to remain competitive. Value networks that encompass the web of relationships generating economic value through complex dynamic exchanges between individuals, groups or organizations are critical for intangible value exchanges and knowledge that will form the foundation for the emerging networked enterprise.

The power of KM is directly proportional to the level with which performance design in PIC is integrated into the tasks of the end user. Those organizations leading the way toward this total integration are aggressively creating and pursuing innovative strategies, models and measures that open their processes to the challenges and value of knowledge infusions. Success will be based on adaptability, not technology. The five industry attributes, identified by the Yankee Group, that offer Internet-related opportunities are high number of Stock Keeping Units (SKUs), frequent transactions, high velocity of information exchange, definable and common product parameters. The other characteristics to consider when determining the likelihood of an industry to go online and its viability in the e-commerce marketplace are tight margins, history of using technology to solve problems, commodity products, critical versus non-critical products, made-to-order versus made-to-stock, product complexity or simplicity, international trading partners. These factors can be addressed by integrating IT and KM initiatives.

Although employee productivity is marked as the primary goal by the heavy investments made in enterprise knowledge management systems in recent years, these investments have been funneled, predominantly, into back-end, systems-based applications that leave the user experience as an afterthought. The KM systems for PIC can be optimized by customizing interface and navigation systems to meet unique business requirements, using a user-centric process of information architecture design, and incorporating information visualization.

To align the organization with a dynamically changing external reality, there is a continuous need to redefine the organizational goals and review the fundamental business principles. The following observations by Steve Kerr, chief learning officer of GE, drives the point home about the anticipation of surprise in this environment of discontinuous change:

> The future is moving so quickly that you can not anticipate it. We have put a tremendous emphasis on the quick response instead of planning. We will continue to be surprised, but we won't be surprised that we are surprised. We will anticipate the surprise.

The role of IT in a knowledge management system cannot be downplayed. Three major contributions of IT to KM are knowledge acquisition, information distribution, and information interpretation. Knowledge acquisition can be achieved through marketing research, competitive intelligent systems, and scenario planning. Information distribution and information interpretation can be achieved through intranets, groupware tools, e-mail, and e-bulletin boards. Integration of technology or its use as a coordinating mechanism would be the key to success of a knowledge management implementation. Organizations should seek to leverage the advantages of both socio-centric and techno-centric approaches in a synergistic manner.

THE EDGE OF KNOWLEDGE: FUTURE KM TRENDS LIKELY TO IMPACT PIC

Several conceptual models have been proposed during the past decade, along with metrics and measurement models. Knowledge management in part deals with human understanding and mental models and how these can be applied effectively in a dynamic business context. Consequently, this is exceedingly complex and we may see advances and refinements in models for a long time to come. According to Wiig (1999), knowledge management promotes the development and application of tacit, explicit, and embedded intellectual capital; that is, leveraging understanding, action capabilities, and the intellectual assets to attain the enterprise's ultimate goals, e.g. to ascertain profitability, ensure long-term viability, or deliver quality services. This perspective of knowledge management suggests a number of developments in coming years that are likely to impact PIC. They include:

(1) A developing area of increasing insight is the role that understanding—or meaning—connected knowledge and abstract mental models play in intellectual work.
(2) Future knowledge management practices and methods will be systematic, explicit, and relatively dependent upon advanced technology in several areas. However, overall we expect knowledge management to become more people-centric as the recognition spreads that it is networking of competent and collaborating people that form the basis for the behavior and success of any organization.
(3) Management and operating practices will change to facilitate knowledge management in many ways. Incentives will be introduced and disincentives eliminated to promote innovation. Effective knowledge exchange, learning and application of best knowledge practices in all work situations.
(4) There will be efforts to embed knowledge management perspectives and considerations in regular activities throughout the enterprise. Natural language processing (NLP) technology will promote the development of cross-language classification and categorization, content visualization and summarization tools, search engine retrieval and multilingual aids.
(5) New practices will focus on desired combination of understanding knowledge, skills and attitudes when assembling work teams or analyzing requirements for performing work.
(6) Most organizations will create effective approaches to transfer personal knowledge to structural intellectual capital. Increased transfer will allow better utilization and leveraging of the intellectual capital.

With advances in NLP and speech recognition, knowledge automation and artificial intelligence technologies are automatically generating middle-tier business logic and decision support systems without the delays and programming costs of traditional IT. Advanced text-mining technologies promise exciting new possibilities and functionalities for the organization, personalization, and retrieval of electronic content. This includes dramatic gains in language understanding that can compete with that of human editors and can even recognize sentiment and intent in text.

DIRECTIONS FOR FUTURE RESEARCH

Knowledge-based systems make control decisions at the implementation level. One such decision is conflict resolution in a PIC environment, where the choice of which rule(s) to fire from a competing set is made. Strategic knowledge, by comparison, is defined at the knowledge level. Strategic knowledge is concerned with the decisions made during the conceptual design phase and is used for deciding the course of action when there are conflicting criteria. A key research issue is how can strategic knowledge be represented for PIC and what kinds of strategic reasoning can be expressed during the design process?

Most of the current design support systems support mainly downstream design in concept formulation. In the 'upstream' stages of design, designers gather fragments of requirements and new information on available devices and gradually or even suddenly come to a new concept of a product. This process has not been supported much by computer systems so far. Since this process of concept formation should receive feedback from downstream design, it will be natural that the upstream support should be connected to downstream support. In the connection, researchers/managers must consider the problems of modelling ambiguity, tacit knowledge and so forth in a PIC environment.

Research into design practice takes many forms—from interviews, field observations, case studies, controlled experiments to simulation trials using AI techniques and more recently protocol studies. Different types of solutions and knowledge require integration of different ways of representation and, therefore, of reasoning.

Research into design practice is not being incorporated into knowledge-based system building in a sufficiently coherent manner. Techniques are required for integration of different AI techniques with each other and conventional systems. Further research is needed into integration and control of coexisting but different views, representation forms, levels of abstraction and complexity. More research is needed into the different strategies applied by designers and their impact on the effectiveness of design. Descriptive studies tell us what happens but not the underlying causes: why does design happen the way it does? In particular, research is needed to support the dynamic character of design especially on a strategic level to enable a more flexible task-sequence and knowledge retrieval.

CONCLUSION

In an economy based on knowledge and intellectual capital, the untapped, unmapped knowledge of organizations is a company's greatest competitive weapon. However, this vital asset is not found on a balance sheet, only rarely managed, and almost never managed skillfully. This paper has emphasized that knowledge and intangible value exchanges by the integration of KM and PIC can help build a strong foundation for the emerging networked economy. There have been many studies in an attempt to understand the dynamics of the manufacturing systems. Throughout the past two decades, many different approaches have been proposed and adopted. A few of the most common examples have been solver technologies such as DSS employed to solve constraint-based systems and discrete-simulation-based systems to simulate possible solutions.

Designing knowledge management tools that provide optimal support for PIC and work performance also requires analysis of function, i.e. how people will use the knowledge. The relationship between people and the information they share can be represented in knowledge artifacts, which are iterative representations of the knowledge of the company. These digitally stored knowledge artifacts and their network of interrelationships can be visualized by organizations that use a variety of knowledge mapping models to facilitate user interaction with highly flexible, associative links or ties of varying dimension. Intelligent decision support systems for information processing. Knowledge-based systems to help the decision-maker in handling disturbances in the plan. However, the decision-maker in the end will have the final responsibility for the decisions that have to be made. As Pflughoeft *et al.* (1996) state, many of the decisions faced by the decision-maker must be made timely in order to avoid adverse consequences and therefore the speed of the decision-making process is perhaps more important than obtaining an optimal solution.

More research in this area is needed. Intelligent support systems within the knowledge-based systems form a basis for supporting production and inventory control and the various disturbances to the plan. The simulator models the goals and objectives of the plan and evaluates the results of various schedules and reschedules. However, the human cognition process cannot be fully modeled.

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