Expert systems applications for productivity analysis

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Keywords

Decision support systems, Measurement, Function evaluation, Productivity rate

Abstract

The purpose of this paper is to describe the process of productivity management and potential expert systems applications at each stage of productivity analysis. Based on literature reviews it discusses the strengths and limitations of these technologies. Describes several tasks in the measurement, interpretation and evaluation phases and examines the appropriateness of an expert systems application. Finds that expert systems applications could be useful in interpretation and evaluation. Focuses on productivity analysis at the organizational-level only. Opines that business managers with limited or no knowledge of productivity models may want to have expert systems applications developed to diagnose problems and take corrective actions in a timely manner. The paper could be useful to business practitioners as well as researchers. Contributions include a detailed description of productivity analysis and how and where expert systems applications could make a difference. Productivity management is critical for long-term business survival.

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Introduction

Productivity is one of the most important performance measures of a business. For CEOs of businesses, productivity and profit margins remain the most important performance indicators in their strategic decision-making, according to *Industry Week's* 27th annual survey in 1998 (Stevens, 1998). Managing productivity within a firm should be an important managerial function if that firm is to remain competitive, but there are serious obstacles to productivity improvement. A survey by the Institute of Industrial Engineers asked practicing industrial engineers, who play a pivotal role in increasing productivity within their firms, to cite the major obstacles to productivity. The top three responses were:

(1) Failure of management to apply proper measurement programs to evaluate productivity improvement.
(2) Failure of management to understand how productivity can be improved.
(3) Failure of management to authorize sufficient manpower to direct productivity improvements (Starr, 1987).

The first obstacle, lack of proper measurement programs, is a crucial one that leads to the second and third obstacle listed above. This survey is rather dated, but even more recently, in the popular article on IT productivity paradox, Brynjolfsson (1993) suggests the same – measurement as one of the main problems. Without proper measurement, there can be no accurate evaluation or productivity analysis. Without productivity analysis, there can be no diagnosis of problems and solutions to improve productivity. This leads to the third obstacle, inadequate support given to productivity improvement and hence, the lost opportunity for productivity improvement. But technologies such as decision support and expert systems can help analyze and diagnose the problems as well as recommend solutions. This paper explores where these technologies can be successfully used in the productivity management process.

Productivity analysis and management

As shown in Figure 1, the steps in the productivity management process include measurement, interpretation, evaluation, choice of corrective or improvement solutions, and implementation of chosen solutions. Productivity analysis comprises the first three phases. Measurement involves selecting the appropriate measurement model or models, setting up the measurement system,

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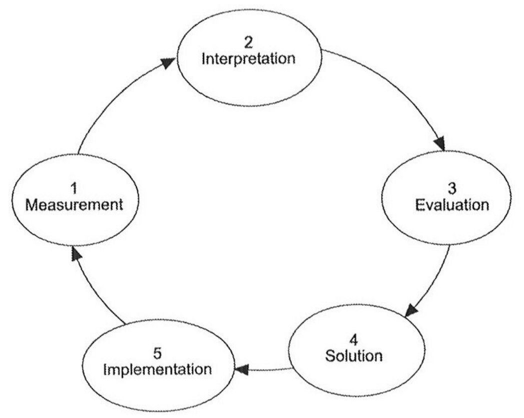
Figure 1 Productivity management process



gathering of relevant data, and generation of performance results. Interpretation is where tentative assessments are made based on the results produced by the measurement model. The numbers and ratios resulting from a model yield nothing more than a set of symptoms. Evaluation leads to identifying the root causes of poor performance based on these symptoms.

The focus of this paper is only up to the evaluation stage of the process, and not the stages of finding the solutions and implementation, which could get unwieldy and probably a topic for future research. In this paper, we first present a review of expert systems applications, then the productivity management process is focused more closely, and finally areas where expert systems could be useful are described.

Expert systems applications

Expert systems are capable of incorporating a human expert's knowledge and analytical ability in a given domain, and are able to explain the analytical methodology on user query. They are more efficient at symbolic processing. They can provide several benefits, including improved decision making, more consistent decision making, reduced design or decision making time, improved training, operational cost savings, better use of expert time, improved product or service levels, and rare or dispersed knowledge captured (Liang, 1988).

Expert systems are becoming an integral part of knowledge management, a topic that appears to be gaining importance lately. An expert system becomes an integral part of the knowledge management system (KMS) if knowledge is stored and used in the form of if-then-else rules (Rasmus, 2000). An organization stores and uses tacit and explicit knowledge. Expert systems are part of the tacit knowledge that an organization possesses. Knowledge management is becoming increasingly important since several authors (Alavi, 2000; Hansen *et al.*, 1999) have emphasized that the economy in developed countries is shifting to a knowledge-based economy. Benefits of knowledge man+agement to organizations are several (Tieperman and Inman, 1994). For example, the Mitre Corporation has realized reduced operating costs, improved staff productivity, and cost avoidance (Young, 2000).

ES applications can be found in a wide variety of areas, including medicine, engineering, and business. A sample of business applications is presented in Table I. There have been several articles listing and categorizing ES applications in business and decision-making (Balachandra, 2000; Blanning, 1984; Coakes *et al.*, 1997; Eom, 1996; Eom *et al.*, 1993; Lin, 1986; Metaxiotis and Psarras, 2003; Mertens and Kanet, 1986; Qureshi *et al.*, 1998; Santhanam and Elam, 1998; Stone and Good, 1995; Wong and Monaco, 1995a; Wong and Monaco, 1995b). Most applications are developed in production/operations management area and least number of applications in the human resources area (Wong and Monaco, 1995a). With the increasing popularity of Internet, web-based applications seem to be growing. Already, there are ES applications on the web for online advice (Huntington, 2000), assistance with communication and control tasks (Macintosh, 1995), and data management (Thede, 2000). An expert system that can interpret the results of a productivity measurement system, diagnose problem areas and suggest solutions can be very valuable for management. However, the only expert system developed specifically for productivity management was the "productivity measurement" system using the total productivity model (Sumanth and Dedeoglu, 1987).

Choosing an appropriate application domain is the important first step in developing an expert system. Some applications are more appropriate than others because of their need for symbolic-processing and the task is performed frequently (i.e. it is not a once-in-a-lifetime activity). These guidelines are kept in mind in determining the potential application of expert systems in productivity management.

Expert systems in productivity management

As stated earlier, the steps in the productivity management process include measurement, interpretation, evaluation, choice of corrective or improvement solutions, and implementation of

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Table I A sample of recent expert system applications

Interpretation	Bowen (2000) – predicts compound properties Eom *et al.* (1993) Neap and Celik (2001) – determines the marginal value of building projects
Diagnosis	Carrasco *et al.* (2002) – diagnoses the state of a pilot-scale wastewater treatment plant Eom *et al.* (1993) – diagnosis in automobile assembly or textile manufacturing Rasuli *et al.* (1999) – assists in brain lesion diagnosis
Prediction	Chiu (2002) – detects, and adapts to changes of customer behavior in internet shopping mall Kannan and Rao (2001) – used in CRM, interactive marketing, and e-commerce Song *et al.* (2001) – predicts customer purchasing behavior
Design	Chau and Albermani (2002) – assists in preliminary design of liquid retaining structures Kowalski *et al.* (2001) – design of ship systems automation Mohamed and Celik (2002) – alternative design, cost estimating, and scheduling in engineering
Planning	Geng *et al.* (2001) – manage petroleum-contaminated sites Kwon and Lee (2001) – efficient enterprise resource planning (ERP) maintenance Mohamed (2001) – productivity adjusted production schedule
Monitoring	Brayant (2001) – evaluating agricultural loans Eom *et al.* (1993) – monitors an automatic stock control system Nelson (1982) – monitors instrument readings in a nuclear reactor
Debugging and repair	Eom *et al.* (1993) – repair and debugging of digital electric circuit cells Grove (2000) – aids in configuring SAP implementations
Instruction	Hollan *et al.* (1984) – teaches the operation of a steam propulsion plant
Control	Eom *et al.* (1993) – control of manufacturing cells Srinivas *et al.* (2001) – blood pressure control Thompson (1999) – pain control and symptom relief in advanced cancer

chosen solutions. Productivity analysis comprises the first three phases. Potential applications in the first three stages are discussed in detail in this section; but the last two stages are left to management's discretion because the number of solutions could be huge and the choices depend on so many other factors. The phase of implementation is primarily a managerial action and planning for the next cycle of the process.

Measurement

Measurement involves the following tasks:
- selection of appropriate measurement model or models;
- setting up the measurement system;
- gathering of relevant data; and
- generation of performance results.

We next discuss the extent to which expert systems applications are appropriate for each of these tasks.

Selection of appropriate measurement model or models

The total number of productivity measurement techniques or models, used from the individual level to the national level, can add up to a hundred or more. In the last 25 years, a number of schemes have been devised to measure productivity at the firm level, so it is not easy to choose an appropriate model. Productivity measurement models can be classified in many ways. Singh *et al.*, 2000 classify them as index measurement models, linear programming-based productivity models and econometric productivity models. Sink *et al.* (1984) classify them as partial-factor, total-factor, and surrogate measures. The model selected, however, depends largely on the taxonomy or criteria one uses for classification. Sink *et al.* (1984) developed a comprehensive taxonomy for the classification of measurement models. Their classification uses two criteria to categorize models, unit of analysis (from individual to national level) and scope of measurement or time frame (from minutes to years). Riel and Shin (1988) presented an expert systems approach to the model selection problem. In the prototype presented, they have used nine attributes in order to choose among 11 measurement models.

Whether the criteria used here by Riel and Shin (1988) are appropriate or not, and the set of models used is sufficient or not, the application of using an expert system for selecting a measurement model itself is very appropriate based on the guidelines presented in the last section, for the following reasons. If designed properly, the task is well bounded and would not lead to combinatorial explosion. The task of selecting models essentially involves symbolic processing. It needs the knowledge of and

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familiarity with all models being considered. Such knowledge is not common in organizations. Depending on the local expertise, there is a significant difference between the best and worst selection, and it may take anywhere from a few hours to a few weeks to select a model. But the task of selecting models is done infrequently, so once a model is selected, it can be used for a long period of time. On the whole, an ES application to select the appropriate productivity measurement technique is appropriate.

If the focus, however, is limited to the firm-level productivity measurement then there is no need for an ES application to choose an appropriate model. In general, total-factor models seem most appropriate for measuring the overall productivity at the firm level. The Total Productivity Model (TPM) by Sumanth (1982) is one such model. There are three other models that may be better than the TPM model because they link productivity performance directly to the bottom line of the firm. First among them is the APC model, which was developed at the American Productivity Centre (Belcher, 1984; Brayton, 1983). Multi-factor Productivity Measurement Model (MFPMM) is a variation of the APC model in that not all factors of production are used (Sink *et al.*, 1984). "Profitability = Productivity+Price Recovery" (PPP) procedure, introduced by Miller (1984a), is yet another model. The PPP and the APC model are similar in some respects; both link productivity to the bottom line of the firm, use the same input data, and result in the same value from their profitability, productivity, and price recovery formulas when applied in certain situations. However, there are substantial differences between the APC model and the PPP model (see Miller, 1984b; Miller and Rao, 1989).

Setting up the measurement system

Once an appropriate model is chosen, it should be set up for a given business unit. It is best set up as a spreadsheet-based system (Rao, 2000) as shown in Figure 2. Once a spreadsheet template is developed using the chosen model, it could be used every time one wants to evaluate performance.

Some expert system development tools provide a reasonably good interface with spreadsheet and database software. This means an expert system can easily read from a spreadsheet, write to a spreadsheet, and let the user go back and forth between a spreadsheet and the expert system. One can also program an ES to create a spreadsheet template with the chosen measurement model. But it could be more difficult than developing a template manually. Developing the template and especially using a series of formulas in the spreadsheet may not be an easy task. But once it is developed, it could be used forever with little changes. That is, this task of developing a measurement system is not done frequently. Hence, this is not an appropriate task for an ES application.

Gathering of relevant data

Implementing a measurement model such as APC or PPP requires gathering any two of quantity, price, or value of each input and output. Inputs are categorized as material, labour, energy, capital, and miscellaneous resources. Outputs are categorized into product lines. Then, a "typical" period or optimal data base line is chosen for the base period (Rao, 1993). To measure the productivity performance of a particular period, the same type of data is gathered for that period. These data are then used in the model to obtain the productivity, profitability, and price recovery contributions of each element and category in dollar terms. In addition, the model can also generate measures such as deflated gross profit and deflated net sales, which are also useful in the productivity analysis.

The data required is dependent on the model chosen. The frequency of data gathering also depends on the situation. Organizations may want to monitor performance monthly, quarterly or yearly. The data may have to be collected manually or it may be available on a computer in a proper format for the measurement system to use it. In any case, this task seems not suitable for expert systems application.

Generation of performance results

Once the data are fed into the measurement system, the results should be computed by the system. The basic data input into a spreadsheet template discussed above (see Table II) would, for instance, lead to the results shown in Figure 3. This task is not suitable for an ES application.

In summary, at the measurement phase, there is only one appropriate ES application – selecting appropriate models. If the measurement is at the firm level, there is no need for any ES application at all.

Interpretation

Interpretation is the phase between measurement and evaluation. It involves making tentative assessments based on the numbers generated by the measurement model (Miller and Rao, 1988). For example, Figure 3 reveals a problem with the price recovery contribution of labor, which is negative

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Figure 2 Basic data in a measurement system

Performance Evaluation Using the PPP Model
Profit Center-1

	QUANTITY					PRICE					VALUE				
	Period-1 Q_1	Period-2 Q_2	Period-3 Q_3	Period-4 Q_4	Period-5 Q_5	Period-1 P_1	Period-2 P_2	Period-3 P_3	Period-4 P_4	Period-5 P_5	Period-1 V_1	Period-2 V_2	Period-3 V_3	Period-4 V_4	Period-5 V_5
Chairs	1,200	1,240	1,260	1,500	1,800	$50.000	$55.000	$60.000	$65.000	$65.000	$60,000	$68,200	$75,600	$97,500	$117,00
Tables	200	210	205	225	250	$350.000	$360.000	$360.000	$400.000	$450.000	$70,000	$75,600	$73,800	$90,000	$112,50
TOTAL SALES											**$130,000**	**$143,800**	**$149,400**	**$187,500**	**$229,500**
Maple Stock	15,000	14,500	14,800	15,000	14,850	$1.100	$1.150	$1.200	$1.400	$1.300	$16,500	$16,675	$17,760	$21,000	$19,305
Varnish	100	100	100	120	110	$20.000	$20.000	$18.000	$15.000	$15.000	$2,000	$2,000	$1,800	$1,800	$1,65
Screws	400	420	450	430	410	$1.200	$1.000	$1.050	$1.080	$1.000	$480	$420	$473	$464	$41
Material											**$18,980**	**$19,095**	**$20,033**	**$23,264**	**$21,365**
Woodworker	3,850	3,910	3,940	3,500	3,400	10.000	13.000	15.000	18.000	18.000	$38,500	$50,830	$59,100	$63,000	$61,20
Finisher	1,000	960	980	900	800	13.000	15.000	16.000	20.000	20.000	$13,000	$14,400	$15,680	$18,000	$16,00
Labor											**$51,500**	**$65,230**	**$74,780**	**$81,000**	**$77,200**
Elctricity	30,000	31,000	32,000	45,000	48,000	0.180	0.180	0.200	0.200	0.200	$5,400	$5,580	$6,400	$9,000	$9,60
Energy											**$5,400**	**$5,580**	**$6,400**	**$9,000**	**$9,600**
Capital Invest.	530,000	535,000	550,000	650,000	700,000	0.048	0.050	0.053	0.053	0.053	$25,440	$26,750	$29,150	$34,450	$37,10
Capital											**$25,440**	**$26,750**	**$29,150**	**$34,450**	**$37,100**
Taxes & insurance	1,000	1,000	975	1,100	1,050	1.400	1.450	1.500	1.540	1.550	$1,400	$1,450	$1,463	$1,694	$1,62
Misc.											**$1,400**	**$1,450**	**$1,463**	**$1,694**	**$1,628**
TOTAL											**$102,720**	**$118,105**	**$131,825**	**$149,408**	**$146,893**
Profits											**$27,280**	**$25,695**	**$17,575**	**$38,092**	**$82,608**

Table II Causes of resource inefficiencies

Labour	Motivation, training, safety, tools, methods, and management decisions
Material	Problems due to material: scrap cost, degree of waste, substitutability, handling care, salvage, tightness of control, quality checks, and value awareness
Energy	Problems due to electric usage: power discipline, leakage, waste, ventilation, loose fittings, proper temperature, substitutive energy source, and excessive reworking
Capital	Problems due to equipment: adequate equipment, automated equipment, appropriate equipment, maintenance, preventive maintenance, scheduling of equipment, and abuse of equipment
Miscellaneous	Problems due to layout: excessive handling, congestion, and low space utilization

throughout. It could be because the labor wage rates were increased or the price of outputs was decreased or both. The labor wage increase seems to be much higher than could be compensated for by the labor productivity and the product price increases, thus ultimately leading to negative profitability. These are some of the tentative assessments that can be made from Figure 3.

There are several existing expert systems that fall into the category of interpretation. An expert systems application for interpretation seems appropriate. There are three steps in the interpretation of measurement results:

(1) Identification of performance results.
(2) Assessment of performance significance.
(3) Interpretation of numerical results in the form of a performance story.

Identification of performance results

The expert system should be able to identify changes in performance results. The primary source of these results is the measurement system. The expert system should, therefore, be able to access this measurement system and obtain the relevant results and other data from the system. The performance changes may be point-to-point or other data patterns such as trends. This identification is not limited to one level, but should take place at various levels such as the macro-level, category-level, and element-level performance. Moreover, it should not be limited to the results of a measurement system such as productivity, price recovery, or profitability contributions alone. It also should be able to use indexes, reported and deflated sales and profit margins, results from other models such as LP models and simulation models, sources such as accounting data, and the user. The data accessed also includes statistical process control data for the time series of each item's performance. Using this data, an ES can identify non-random or assignable variations such as trends. The ability to access and use data from various sources can facilitate more precise identification of problems.

Assessment of performance significance

Once the performance results are identified, an ES should be able to assess the significance of the performance changes. Information about problem significance allows problems to be ranked according to their severity. Without such

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Figure 3 Performance results from the measurement system

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	A	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH	BI
1																
2																
3		PRODUCTIVITY					PRICE RECOVERY					PROFITABILITY				
4		Period-1	Period-2	Period-3	Period-4	Period-5	Period-1	Period-2	Period-3	Period-4	Period-5	Period-1	Period-2	Period-3	Period-4	Period-5
5		Prodv1	Prodv2	Prodv3	Prodv4	Prodv5	PRec1	PRec2	PRec3	PRec4	PRec5	Prof1	Prof2	Prof3	Prof4	Prof5
6	Chairs															
7	Tables															
8	**TOTAL SALES**															
9	Maple Stock	0	1,248	834	3,089	6,336	0	329	368	(291)	3,488	0	1,577	1,202	2,798	9,824
10	Varnish	0	85	74	(26)	548	0	127	424	1,111	1,333	0	212	498	1,085	1,881
11	Screws	0	(4)	(42)	54	168	0	115	121	174	269	0	111	79	228	437
12	**Material**	**0**	**1,329**	**870**	**3,173**	**7,035**	**0**	**571**	**910**	**938**	**5,107**	**0**	**1,900**	**1,780**	**4,111**	**12,142**
13	Woodworker	0	1,029	534	10,707	18,898	0	(9,272)	(15,389)	(18,178)	(12,131)	0	(8,243)	(14,855)	(7,471)	6,767
14	Finisher	0	1,070	744	3,734	7,462	0	(1,090)	(1,484)	(2,984)	(512)	0	(20)	(740)	750	6,950
15	**Labor**	**0**	**2,099**	**1,292**	**14,508**	**26,315**	**0**	**(10,362)**	**(16,887)**	**(21,229)**	**(12,598)**	**0**	**(8,263)**	**(15,595)**	**(6,721)**	**13,717**
16	Elctricity	0	48	(159)	(1,689)	(1,221)	0	345	(35)	477	1,154	0	393	(194)	(1,212)	(67)
17	**Energy**	**0**	**48**	**(159)**	**(1,689)**	**(1,221)**	**0**	**345**	**(35)**	**477**	**1,154**	**0**	**393**	**(194)**	**(1,212)**	**(67)**
18	Capital Invest.	0	836	(13)	(998)	1,354	0	555	99	3,240	6,457	0	1,391	86	2,242	7,811
19	**Capital**	**0**	**836**	**(13)**	**(998)**	**1,354**	**0**	**555**	**99**	**3,240**	**6,457**	**0**	**1,391**	**86**	**2,242**	**7,811**
20	Taxes & insurance	0	59	87	122	454	0	40	59	203	390	0	99	146	325	844
21	**Misc.**	**0**	**59**	**87**	**122**	**454**	**0**	**40**	**59**	**203**	**390**	**0**	**99**	**146**	**325**	**844**
22	**TOTAL**	**0**	**4,372**	**2,148**	**16,929**	**36,824**	**0**	**(8,853)**	**(15,924)**	**(18,184)**	**(2,376)**	**0**	**(4,481)**	**(13,776)**	**(1,255)**	**34,448**
23	**Profits**															

information, minor problems and serious problems would receive the same attention. Moreover, some variations in performance may be purely random and without any assignable causes. Hence, an expert system for productivity analysis should be able to identify non-random variations and make a value judgment about the significance of the problem such as very serious, serious, significant, moderate, minor, insignificant or no problem. Conversion of numerical values into such descriptive terms makes them more meaningful to a manager and represents an extremely useful feature from a management standpoint. Without this capability, a great deal of time must be spent in arriving at the same results. Expert systems technology, because of its strength in symbolic processing, can play an important role in applications at this stage.

Interpretation of numerical results into a performance story

As shown above, value judgments are very useful in analyzing productivity performance. They would be even more useful if the results were presented to the user as a complete performance "story" rather than just a number or a single word, such as *serious*. It is valuable for the system to display at least one-sentence statement such as "There is a *serious profitability-problem* with wood-workers". However, a performance story needs to be much more than one sentence. The expert system should tell the user about the performance change (positive, negative, or no change), the magnitude of this deviation (say −$200,000 or +$100,000), whether the deviation is non-random (because of a trend or something else), the significance of the current-period performance (e.g. lowest or highest in the time series), the overall assessment of the area (e.g. serious, significant, or minor problem), and any qualifications to the statements (e.g. certainty factors). It should also tell the causes of performance change and possible corrective actions. Moreover, it should weave all this information into a "story" rather than merely issue a series of disjointed statements. This type of comprehensive narrative portrayal is very useful if an expert system is to provide quick, accurate and understandable productivity analysis to a manager.

Evaluation

Interpretation, although useful, is just one step in the analysis. The numbers and ratios resulting from a model yield nothing more than a set of symptoms. Evaluation leads to identifying the real causes of poor productivity, price recovery, and profitability. To find the causes of symptoms, evaluation requires interaction between the productivity analyst and the manager of the profit centre. The answers are not obvious because they may depend on many variables such as product-mix, volume, and resource-mix, any of which might have

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changed because of a number of factors such as market conditions, employee morale, union problems, safety, overtime, scheduling problems, and inventory problems. For a more accurate diagnosis, it is often necessary to examine other performance measures such as effectiveness, efficiency, quality, quality of working life, and innovation, because these measures influence productivity, and thus the root problems that would be uncovered through productivity analysis.

Association of causes with effects

There are several very successful expert systems in the area of diagnosis. Diagnosing the root causes of the problems in an organization seems to be a perfect ES application. The ES should be able to determine the causes of identified problems. For example, if labour productivity has been identified as a problem, then the system should be able to determine that the problem is motivation, training or whatever the case is. An expert system can determine such a cause by gathering information electronically from company databases or manually from the user. For example, if absenteeism and tardiness point to motivation as the cause, actual absenteeism and tardiness data for recent periods can be obtained from company databases. If the relevant data are not in the company databases, the user must provide them. The performance changes that result from the measurement model can be attributed either to inefficiencies in the use of production resources or to exogenous "uncontrollable" factors outside the immediate influence of plant management. The root causes of the first category are controllable to a large extent. For example, labor inefficiency may be caused by poor training, which can be corrected (or controlled) by better training.

The second category of performance changes, namely "uncontrollable" factors, includes effects such as volume decline and resource inflexibility. Changes in volume may be due either to changes in demand or to management's production and marketing policies, issues that are outside the immediate control of a production manager. Resource inflexibility is also an uncontrollable factor. That is, management cannot vary resources on a one-to-one basis with output changes because some resources are fixed and some are variable. A person unaware of these relationships may misinterpret the results. Hence, an expert system would be very useful in proper evaluation of root causes.

Causes of resource inefficiencies

In general, resources can be categorized as labour, material, energy, capital, and other. The following list (Table II) is an illustration of the potential root causes of inefficiencies in these categories. The knowledge for preparing this list comes from several sources such as expertise of people with several years of experience in the industry, literature, and productivity checklists (Taylor, 1985).

This inventory of causes of productivity problems is by no means exhaustive. Further, it is important to note that the classification of causes may not exactly follow along resource boundaries. The same cause(s) can affect different resource categories. For example, poor training can cause more scrap as well as longer labour hours, thus affecting both material and labour productivity.

As stated previously, there are several successful expert systems now in use in the area of diagnosis (see Table I, and Wong and Moncao (1995b)). Since evaluation involves determining underlying causes, it is a very appropriate expert systems application.

Selection of improvement solutions

Some of the improvement solutions may include expert systems applications, of which there are virtually hundreds of applications. For instance, if the problem is with layout, one could use an expert system such as *FADES*. There are several ES applications for improving forecasting (Nikolopoulos and Assimakopoulos, 2003), production scheduling (Metaxiotis *et al.*, 2002), customer service (Eppinette and Inman, 1997), and other tasks (Wong and Monaco, 1995b).

An ES for productivity management should be able to recommend corrective actions based on the causes identified above. A simple cause and treatment might be, for example, that if lack of training is lowering labour productivity, then training is the appropriate corrective action. However, a comprehensive treatment may not be that simple. In the first place, there may not be a single cause. Sometimes, when several causes are put together, there may be a single appropriate treatment while on the other hand one cause may require several types of treatments. So a specific treatment for each cause may not be wise. An expert systems application for choosing the right solutions to correct the identified problems seems ideal, but because of the complexities involved in finding the right solutions, it is left alone for now. An effective, non-controversial ES application may be very difficult to develop, and so is left for future research.

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Table III Potential applications of expert systems in productivity management

	Steps in the productivity management				
	Measurement	Interpretation	Evaluation	Solution	Implementation
Interpretation		✓			
Diagnosis			✓		
Prediction					
Design	✓			✓	
Planning				✓	✓
Monitoring	✓	✓			✓
Debugging and repair			✓		
Instruction	✓	✓	✓	✓	✓
Control				✓	✓

Implementing improvement solutions

Implementing improvement solutions is primarily a management action. Expert systems might help if the solution involves a complicated implementation process. But their role seems to be limited. This also could be another area for future research.

Summary of potential applications

The proposed potential of expert system use in different phases of the productivity management process is summarized in Table III. The table shows different categories of expert systems that may be more applicable at each phase.

At every phase of the productivity management process, ES applications can instruct the users. In the measurement phase, an ES application can help select the right model(s) for designing the measurement system. ES can also help monitor measurement results. In the interpretation phase, an ES can continuously monitor and interpret the performance results from the measurement system and other sources. In the evaluation phase, an ES can diagnose the root causes of the problems.

Solution and implementation phases are beyond the scope of this paper, and are left for future research for the reasons stated previously. Generally speaking, the ES applications for debugging and repair, planning and design, and control may be useful in the solution phase. Finally, in the implementation phase, expert systems can be used for planning, monitoring and control.

Conclusion

Although productivity management is essential for long-term survival of a business, there are serious obstacles to its practice because many managers may not have the time to analyze productivity and take necessary corrective actions in time. The application of expert systems technology can help solve this problem. Expert systems can assist managers in many phases of the productivity management process. This paper has described each stage of this process and discussed the fitness of expert systems applications. Examples of existing applications illustrate the possibilities and the strengths of these applications. This research may lead to the development of several new expert systems applications, and as a result, improved productivity in the business world.

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