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Selecting IT Applications in Manufacturing: A KBS Approach

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SELECTING IT APPLICATIONS IN MANUFACTURING: A KBS APPROACH

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ABSTRACT

The use of the right type of Information Technology (IT) applications or manufacturing systems is expected to usher in a competitive advantage [3][5][27][42]. Selection of the right type of IT application is, however, a challenging task. When a company, with a given dominant process structure, emphasizes two or more competitive priorities, such as quality, product flexibility, etc., an unaided manager faces a complex decision problem in choosing from alternative IT applications available in the areas of product design through distribution. In this paper, we present a Knowledge Based System (KBS) that would assist managers with the identification of IT applications that are consistent with both the competitive priorities and the process structure. Validation of the system illustrates that its performance is consistent with the human experts, and it has the potential to facilitate effective and swift decision-making in the selection of appropriate IT applications that best match an organization's manufacturing strategy.

Key words: Information Technology; Manufacturing Strategy; Rule Induction; Operations Management; and Expert Systems.

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1. INTRODUCTION

Shaped by the economic environment of the time, organizations in the past worked on the principles of division of labor to meet an unrelenting demand for goods and services. This approach resulted in the division of manual labor on the shop floor and professional labor in the upper echelons of the organization [17]. Specialists, assigned to different functional areas, adopted ways and measures, including the use of information technology (IT), to enhance efficiency of their respective units. IT was then viewed as a means of automation to improve productivity of various components of an organization.

In contemporary environment, however, IT is seen as a vehicle to gain a competitive advantage [14, 25]. It is important to note that mere introduction of IT, in and of itself, does not create a competitive advantage [24]. On the other hand, use of the right type of IT application for a given company may lend a competitive edge [35]. The importance of alignment between IT applications and a company's strategy has been noted extensively in the literature [3, 5, 26, 27, 34, 45].

The need for alignment between IT applications and strategy is profound in the manufacturing sector, where it is reported that "over half a firm's capital expenditures involve IT" [11, p.123]. The extent of investment in information technologies in manufacturing and process industries was further underlined by Malcolm Forbes, Jr. in an interview with Kevin Parker [41]. Nevertheless, the returns from these IT investments are not compatible as observed by two-thirds of Fortune 100 companies' chief executive officers [49]. This could be due to a lack of alignment or misalignment between IT applications and the company's strategy. Specifically, in manufacturing-the focus of this paper- not all users of the Material Requirements Planning (MRP) system, a widely used IT application [11], derive potential benefits of the system [9]. The failure of these MRP users is attributed to the misapplication of MRP, that is the misalignment between manufacturing priorities and characteristics of the IT application - MRP [32].

The IT applications in the manufacturing strategy literature are also known as Advanced Manufacturing Technologies (AMTs) or Advanced Manufacturing Systems (AMSs), and researchers have vehemently emphasized the need for careful selection and adoption of these technologies. Boyer et al. [7] observed that investments in these AMTs - CAD, MRP, etc. - are more likely to yield better performance if they are consistent with improvements in the manufacturing infrastructure – worker empowerment, quality leadership - of the company. With regard to the use of Just in Time (JIT) and MRP2, Skinner [54] states: “[These] are marvelous creations, but they are very different and need to be chosen for relevancy to the process and to other elements of a coherent infrastructure” (p. 18). Based on the work of Grant et al. [16], Upton [59] notes that some of these technologies are complementary while others are alternatives, and companies should evaluate them with regard to the degree of automation, extent of integration, and the flexibility they afford. Clark [10] argued that the capabilities of these systems should be integrated with strategic needs of manufacturing. Hayes and Pisano [18] observed that companies which harness these AMTs in the service of a manufacturing strategy are likely to gain a competitive advantage. None of the studies, however, proposed any mechanism to align these systems or technologies with manufacturing strategy.

In this paper, we propose the use of a Knowledge Based System that would assist in identifying the right type of IT applications for a manufacturing company with a given manufacturing strategy. Knowledge Based Systems (KBSs) are computer based information systems, which embody the knowledge of experts, and manipulate this expertise to solve problems at an expert level of performance [47]. These systems have the ability to encode and manipulate expert knowledge through inference paradigms, such as forward and backward chaining, to intelligently produce expert diagnosis [63]. KBSs have been used effectively in domains where decision problems are open-ended and where no clear-cut methods are available to solve them [56]; as well as where human expert knowledge is scarce [21]. In the area of manufacturing, KBSs have been used extensively in areas such as plant maintenance, process monitoring, process planning, and production scheduling applications. In the recent past KBSs have begun to emerge as important decision aids to solve strategic organizational problems [4, 62]. These systems have proven to be highly beneficial to organizations, especially in terms of affording faster reaction time to changing competitive and market conditions [43]. For instance, Jungthirapanich [28] observed that a KBS took only ten minutes to make a facility location decision while companies take an average of eight months to arrive at the same decision.

The rest of this paper is organized in the following manner. The next section briefly describes the manufacturing strategy and the underlying constructs relevant to this paper. Some theoretical frameworks that align strategy and IT applications in the realm of manufacturing are then reviewed. Next, the applicability of a KBS to this decision-making process is discussed that is followed by the steps for designing the system. Finally, the conclusions, implications for managers, and directions for future research are discussed.

2. LITERATURE REVIEW

This section first describes the dimensions of manufacturing strategy - competitive priorities - and the process structures. The term IT application, as used in manufacturing, is then described. The frameworks linking IT applications, competitive priorities, and process structures are briefly reviewed.

2.1. Manufacturing Strategy: Competitive Priorities and Process Structures

The manufacturing strategy, derived from corporate and business strategies, outlines the choice of a 'dominant attitude' also called the competitive priority for a company [19]. The competitive priorities are also referred to as the dimensions of manufacturing strategy or the content of manufacturing strategy [55]. The four basic competitive priorities are: Cost, Quality, Flexibility, and Delivery [8, 20, 60]. These priorities are no longer treated as tradeoffs, as originally perceived by Skinner [51, 52]. Contemporary researchers, including Ferdows and De

Meyer [15], Corbett and Wassenhove [12], and Noble [40], believe that a company can simultaneously emphasize and do well on multiple competitive priorities. Specific measures to operationalize these competitive priorities are described in the next section. For a detailed description of these priorities, please refer to Leong, Snyder and Ward [33]. The four generic process structures used in manufacturing include Job shop, Batch, Assembly Line, and Continuous Flow [23].

2.2. IT Applications in Manufacturing

The term IT is viewed in a broad sense after Cooper and Zmud and "it refers to any artifact whose underlying technological base is comprised of computer or communications hardware and software"[11, p.123]. Parsons [42] used the term IT to represent systems in various application areas. Under manufacturing function, the application areas included design, purchasing, inventory management, etc. Traditionally, Production and Operations Management has been considered a promising area for IT applications which include both Decision Support Systems (DSSs) and KBSs [46, 58]. As a result, there are numerous IT applications, such as Computer-Aided Design (CAD), MRP, Distribution Requirements Planning (DRP), etc., available to help make better decisions in almost all topical areas of manufacturing, ranging from product design to distribution of products.

2.3. Frameworks Linking Competitive Priorities, Process Structures, and IT Applications

Researchers first adopted a two-dimensional approach to link either (i) Competitive priorities with process structures [20, 23, 53], or (ii) IT applications with competitive priorities [42], or (iii) IT applications with process structures [11]. Later, Berry and Hill [6] proposed a three-dimensional framework for linking manufacturing, planning and control (MPC) system design to strategy. The three dimensions used were market requirements, manufacturing task, and manufacturing process. The salient features of the aforesaid frameworks are summarized in Table 1.

Inset Table 1 about here

Kathuria and Igbaria [30] developed a three-dimensional integrated framework that spans IT applications in areas ranging from product design through distribution. Their framework suggests that in a manufacturing environment, the IT application should be aligned with both the competitive priority and the process structure of the organization. They observed that by achieving this alignment, an organization would gain a competitive edge. Their framework is based on the premise that the process of matching IT applications to competitive priorities involves identification of tasks corresponding to competitive priorities (Cost, Quality, Dependability, Flexibility, etc.) and compatible process structures (Job, Batch, Line, Continuous). By matching key managerial tasks specific to a competitive priority and the compatible process structure, with characteristics of IT applications, they developed an integrated framework that links competitive priorities, process structures, and IT applications (see Table 2).

Inset Table 2 about here

IT applications, available under each topical area in manufacturing, are assessed for their appropriateness to pursue certain competitive priorities. The examples of companies or process structures that are most suited to adopt these IT applications, to pursue corresponding priorities, are also provided. If key manufacturing tasks underlying some competitive priorities do not necessitate the use of a particular IT application over another, the corresponding cell in their framework is either left blank or an IT application is recommended based on its compatibility with the process structure alone. The three dimensional frameworks exploit synergies among three vital components - IT applications, competitive priorities, and process structures - given that all possible pairs (two dimensional models) have been argued to be advantageous. The expanded frameworks are more comprehensive but difficult to utilize since each additional dimension adds complexity to the decision making process. To overcome added intricacy, we propose a KBS that would help practitioners in identifying the right IT applications given their manufacturing competitive priorities and process structures. Since Kathuria and Igbaria [30] framework is more recent and extensive, it was selected as a basis for the design of the KBS developed in this paper.

3. KBS DEVELOPMENT ENVIRONMENT

This section first identifies the KBS development environment, which includes an appropriate method for developing the proposed KBS. The development of the KBS, including the choice of procedure for knowledge acquisition and for rule generation, the procedure for selecting IT applications, the inputs to the KBS, and the way induction rules are created, is then discussed.

3.1. KBS Development

As illustrated in Figure 1, a KBS has four major components, namely the knowledge base, inference engine, user-interface, and the explanatory subsystem (see [57] for an in-depth review of KBSs). The transfer of knowledge into the knowledge base by the knowledge engineer can be accomplished through either programmed- or auto-learning. The programmed systems require an explicit input of decision rules to build the knowledge base. The auto-learning approach on the other hand, creates rules automatically after exposure to cases or examples that are acquired from human experts. Since this approach permits human experts to illustrate their decision making process by means of examples or cases, rather than by exhaustively detailing every decision rule, it is considered a more efficient approach than the latter [1, 57]. In view of the complexity of selecting an appropriate IT application consistent with manufacturing strategy, the auto-learning approach was used in this study.

Insert Figure 1 about here

Once the knowledge acquisition stage was complete, the examples were used to generate a set of classification rules that map the underlying decision-making process of selecting IT application that match the manufacturing strategy. These rules were created through a widely used inductive algorithm, which is defined *"as a process of going from an initial hypothesis about specific observations about objects to an inductive assertion that accounts for the observation"* [36]. Specifically the algorithm used in this study is Quinlan's [44] Inductive Dichotomizer (ID3) which has been applied extensively to problems with deterministic data.

3.2. Procedure for Creating the Rules

A multi-step approach, as suggested by Arinze [2], is used for developing the rules, which selects an IT application that aligns with an organization's competitive priorities and process structure. First, a description of the current problem, in terms of the important attributes that determine the competitive priorities and the process structure, is presented to the system.

Second, the most appropriate IT applications are entered for each case, under various functional areas, which align with an organization's competitive priorities and the process structure. Finally, the induction rules are generated.

3.2.1. Description of the current problem. The cases used in this study were mapped using five attributes which gauge the competitive priorities (Quality, Delivery, Flexibility, and Cost) and the process structure (Job, Batch, Line, and Continuous) of an organization. The competitive priorities of an organization are assessed using the importance attached to fifteen items that operationalize the first set of (four) attributes. These items, taken from Kathuria, Porth and Joshi [31]; Miller and Roth [37]; Morrison and Roth [38]; Nemetz [39]; Safizadeh, Ritzman, Sharma and Wood [50]; and Wood, Ritzman and Sharma [61] are listed in Figure 2. Importance attached to each item is measured as low, medium, or high. If the importance is rated high on any of the items used to operationalize a priority, the organization is considered to be emphasizing that priority. Consistent with the findings of Ferdows and De Meyer [15], and Noble [40], it is possible that a company might highly emphasize several competitive priorities. Once the competitive priorities of an organization are identified, its process structure is then examined for compatibility with the priorities emphasized. These attributes are illustrated in Figure 2 and discussed briefly below.

Insert Figure 2 about here

Quality: There are as many definitions of this attribute as there are 'quality gurus' [48]. The most widely used definition of quality in manufacturing, however, is: Meeting and exceeding the needs of consumers with a defect free product. Measurement was in terms of two factors, - *Quality of Design* emphasizes product performance, while *Quality of Conformance* emphasizes the level of consistency [29]. These two factors are measured using five items shown in Figure 2.

Delivery: In manufacturing, this attribute implies that products are delivered quickly, i.e., *Delivery Speed*; as well as on-time to customers, i.e., *Delivery Reliability* [60]. The emphasis on *Delivery Speed* and *Delivery Reliability* is captured using two items each.

Flexibility: The two commonly known dimensions of flexibility are *Product Flexibility*, and *Volume Flexibility*. *Product Flexibility* requires a company to have the ability to successfully handle a wide product range, while the latter refers to the company's ability to similarly adjust its output capacity as the need arises [22]. The emphasis on *Product Flexibility* is measured using three items and the emphasis on *Volume Flexibility* is captured using two items.

Low Price: This attribute considers a company's priority to be tight cost control. The emphasis on Low Price is captured through the 'ability to provide a product at low costs in a price-sensitive market.

Process Structure: This attribute considers the dominant process structure used by a company. Manufacturing companies predominantly use one of the following: job, batch, line, or continuous type. A job shop takes on low-volume orders from a whole range of customers whereas in a batch shop orders are of relatively higher volume from fewer customers. A line structure is dedicated to the needs of a single product or a small range of products. A continuous process structure is designed to process a very high volume of a basic material through successive stages into one or more products.

3.2.2. Enter the most appropriate IT applications. Once the competitive priorities are ascertained and examined for compatibility with the dominant process structure of the company, appropriate IT applications are identified from Table 2. For instance, in example # 1 in Table 3, the competitive priorities based on the response to fifteen items (listed as A through O) are product flexibility and volume flexibility; a compatible process structure is a job shop or a batch shop; and the most appropriate IT application in the inventory management area is MRP or OPT. These IT applications best match the competitive priorities and the process structure of the given company. Similarly, IT applications in other functional areas, ranging from product design through distribution, are identified. The outcome of each case, as entered into the KBS, is the type of IT application in a given functional area, that provided the best alignment between a company's competitive priorities and its process structure.

Insert Table 3 about here

3.2.3. Creation of induction rules. Using the above steps, 70 cases were created which were, in turn, used to generate the induction rules using the ID3 algorithm. The objective of this algorithm is to develop a decision tree that requires a minimum number of attributes and a predefined classification of the example. To minimize a decision tree, ID3 chooses the attribute whose discriminating power is the largest among them. The Appendix describes the ID3 induction algorithm. The induction rule is illustrated in Figure 3.

Insert Figure 3 About Here

4. KBS CONSULTATION ENVIRONMENT

4.1. Validation of the User Interface

Two user groups, namely five manufacturing mangers and two experts in the field of Production and Operations Management, evaluated the user interface of the KBS. Both groups were provided with questionnaires to provide feedback about validity of the user interface. Three factors—*ease of use, timeliness,* and *usability* that typically affect the merit of the interface were evaluated. Each of the factors was evaluated on a scale of 1-5, where 1 is very unacceptable and 5 is very acceptable. All seven respondents rated ease of use as 5, while timeliness and usability scored 4.86 and 4.71 respectively. Since the results of the evaluation showed that both groups evaluated the KBS at higher than average acceptable level, the authors are of the opinion that the user interface was successfully validated.

4.2. Validation of the Knowledge Base

Validation of the knowledge base was considered essential in order to verify the model's usefulness within the manufacturing industry. Currim [13] asserts that induction rules can be validated on three dimensions, namely structural validity, diagnostic validity, and predictive validity.

4.2.1. Structural Validity. The structural validity was conducted in two phases. First the output of the KBS was compared with the Kathuria and Igbaria [30] framework to ensure that the KBS model did not violate any of the relationships. Then the KBS was provided with scenarios which were either infeasible or mutually exclusive. The system responded appropriately in stating that it was not possible to recommend an IT application under the conditions provided.

4.2.2. Predictive Validity. The KBS was tested against a hold-out sample of 25 simulated cases that were not used in the creation of the induction rule. The holdout sample predicted the IT application correctly with an accuracy rate of 96 percent, thereby confirming the predictive validity of the KBS.

4.2.3. Diagnostic Validity. To test the diagnostic validity of the KBS, it was tested with three manufacturing consultants. These consultants had conducted assignments related to the selection of IT applications in the areas of capacity planning and inventory management in a laptop assembly unit; demand management and distribution system in a paper board manufacturing plant; and inventory management and shop floor control in a machining shop. The consultants were bound by an agreement between their employer consulting firms and the client organizations to conceal their identity and not share any proprietary information. They, however, agreed to summarize relevant information from their projects, which is included in Table 4.

Insert Table 4 about here

The consultants were asked to use the KBS and see if its recommendations were in line with what they had developed and implemented for their clients. Summarized case profiles, the

IT application proposed by the KBS, and consultants' response to KBS's recommendation are provided in Table 4. As can be observed, the KBS performed in line with the expectations of consultants who admired its usefulness. The consultants agreed that the KBS was an effective tool for identifying IT applications that were consistent with the competitive priorities as well as the process structures of manufacturing companies.

5. CONCLUSIONS

The importance of matching IT applications or manufacturing systems with the competitive strategy of a company is consistently emphasized. Few theoretical frameworks have been proposed to help managers select IT applications that are consistent with their competitive priorities and the process structure. Managers, however, find it difficult to use these frameworks since no mechanism exists to identify competitive priorities or the process structure of a company, and managers have more difficulty in identifying their priorities when seen as individually distinct entities as in the framework.

This study presented a KBS which is designed to assist managers with selecting IT applications that are consistent with both the competitive priorities and the process structure of a manufacturing company. The KBS is developed using the 1st class KBS shell that uses ID3 induction algorithm to generate rules through induction. The knowledge base was created using the rules extracted from a recently developed three-dimensional framework that links IT applications with competitive priorities as well as the process structure of a manufacturing organization. The transfer of knowledge into the knowledge base was accomplished through auto-learning.

The induction rules were validated on three dimensions, namely structural validity, diagnostic validity, and predictive validity. Validation of the KBS illustrates that the system's performance is consistent with the human experts. It, thus, can support and enhance the effectiveness of organizations in the selection of appropriate IT applications. The KBS will help avert misapplication of IT applications - a recurring problem in manufacturing industries. The choice and use of the right type of IT application may offer the user company the competitive edge it seeks. Furthermore, managers can get authentic advice from the KBS in a timely and cost effective manner.

It may be noted that any attempt to recreate the system by a third party, based on the information provided in this paper, might lead to slightly different recommendations than in the original KBS. Further, as competitive priorities are increasingly viewed as mutually supportive, and not as trade-offs, future research should attempt to incorporate this new thinking in future endeavors. As companies move towards simultaneously emphasizing multiple competitive priorities, future research could also benefit from rating the suitability of IT applications on a Likert scale rather than a binary scale, as done in this KBS. The proposed KBS should be refined and updated in the future to include new competitive priorities and other factors, as they become available.

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Table 1

An Overview of Frameworks Linking Competitive Priorities, Process Structures, and IT Applications

Linkage	Reference(s)	Salient Points
Competitive Priorities and Process Structures	[19, 20, 22, 53]	Different process structures are considered to have an inherent advantage in pursuing certain competitive priorities.
IT Applications and Competitive Priorities	[42]	Companies following a particular competitive priority should use certain IT applications to gain a competitive advantage.
IT Applications and Process Structures	[11]	The choice of an IT application, such as an inventory management system, is influenced by its process structure.
Market requirements, Manufacturing task, and Manufacturing process	[6]	Manufacturing planning and control (MPC) system design should be consistent with the manufacturing process as well as the market requirements.
IT Applications, Competitive Priorities, and Process Structures	[30]	IT applications should be aligned with both the competitive priorities as well as the process structure of a manufacturing company.

Table 2

Competitive Priorities, Compatible Process Structures, and

Corresponding IT Applications

Competitive Priority	Compatibility with Process Structure: Job ...... Continuous	Corresponding IT Applications by Functional Area: Design	Demand Mgt.	Capacity Planning	Inventory Mgt.	Shop Floor	Quality Mgt.	Distrib--ution
Low Cost	Low _____ High*	DFM	MTS	CPOF	JIT; ROP-C	ALB	QC; QE	Q,R
Quality -Conformance -Less Defectives	Low _____ High	DFM			JIT	ALB	QC	
Product Flexibility	High _____ Low		ATO	CBP; CRP	MRP; OPT	Seq./ Sched.		DRP
Volume Flexibility	High _____ Low		ATO	CBP	OPT			DRP
Quality - Design - Features	High _____ Low	CAD	MTO				QP; QFD	
Delivery Reliability	High __ ____Low	CAD	MTO	RP	OPT	Seq./ Sched.	QP; QFD	DRP
Delivery Speed	Low ______ High		MTS	CPOF	ROP-P	ALB		

* - Continuous type of process structures are considered to have an advantage in pursuing low cost as a competitive priority.

Legend:

DFM -	Design for Manufacturability;	**CAD** -	Computer aided design;
ATO -	Assemble-to-order;	**MTO** -	Manufacture-to-order;
MTS -	Make-to-stock;	**CPOF** -	Capacity Planning using Overall Factors;
CBP -	Capacity Bills Procedure;	**CRP** -	Capacity Requirements Planning;
RP -	Resource Profiles;	**JIT** -	Just-in-Time;
MRP -	Materials Requirement Planning;	**OPT** -	Optimized Production Technology;
ROP-C -	Reorder Point (Continuous);	**ROP-P** -	Reorder Point (Periodic);
ALB -	Assembly Line Balancing;	**Seq./Sched.** -	Sequencing and Scheduling;
QC -	Quality Control;	**QE** -	Quality Engineering;
QP -	Quality planning;	**QFD** -	Quality Function deployment;
Q,R -	Continuous Review System;	**DRP** -	Distribution Requirements Planning.

This Table is adapted from Kathuria and Igbaria (1997).

Table 3
Simulated Case Scenarios - A Sample

	Item							Inferred	Compatible	IT Applications			
Case #	**A**	**B**	**C**	**. . .**	**M**	**N**	**O**	**Competitive Priority**	**Process Structure**	**. .**	**Inventory**	**. . .**	**Distribution**
1	Low	Low	Low	. . .	Low	High	High	FV & FP	Job/Batch	. .	OPT/MRP	. . .	DRP
2	High	Low	Low	. . .	Low	Low	Low	Cost	Line/Cont.	. .	JIT/ROP-C	. . .	Q,R
3	Low	Low	Low	. . .	Low	Low	Low	FP	Job/Batch	. .	OPT/MRP	. .	DRP
4	Low	Low	Low	. . .	Med	Low	Low	FP	Job/Batch	. .	OPT/MRP	. . .	DRP
5	Low	Low	Low	. . .	Low	Low	Low	QD	Job	. .	OPT	. . .	DRP
6	Low	Low	Low	.	High	High	Low	FP & FV	Job/Batch	. .	OPT/MRP	.	DRP
7	Low	Low	Low	.	Low	Low	Low	QD	Job	. .	OPT	.	DRP
8	Low	Low	Low	.	Low	Low	Low	DS	Line/Cont.	.	ROP-P	.	Q,R
9	Low	Low	Low	.	High	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
10	Low	Low	Low		Low	Low	Low	DS	Line/Cont.	.	ROP-P	.	Q,R
11	Low	Low	High		Low	Low	Low	DR	Job	.	OPT	.	DRP
12	Low	Low	Low		Low	High	Low	FV	Job/Batch	.	OPT	.	DRP
13	Low	Low	Low		High	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
14	Low	Low	Low		Med	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
15	Med	Low	Low		Low	Low	Low	Cost	Line/Cont.	.	JIT/ROP-C	.	Q,R
16	Low	Med	High		Low	Low	Low	DR	Job	.	OPT	.	DRP
17	Low	Low	Low		Low	Low	Low	QC	Continuous	.	JIT	.	Q,R
18	Low	Low	Low		Low	Med	High	FV	Job/Batch	.	OPT	.	DRP
19	Low	Low	Low		Low	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
:	:	:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:	:	:
64	Low	Low	Low	:	High	High	Low	FP & FV	Job/Batch	.	OPT/MRP	.	DRP
65	Low	Low	Low		Low	Low	Low	QD	Job	.	OPT	.	DRP
66	Low	Low	Low		Med	High	Low	FP & FV	Job/Batch	.	OPT/MRP	.	DRP
67	Low	Low	Low		Low	High	Med	FV & FP	Job/Batch	.	OPT/MRP	.	DRP
68	Low	High	Low		Low	Low	Low	QD & DR	Job	.	OPT	.	DRP
69	Low	Low	Low		High	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
70	Low	Low	Low		Low	High	Med	FV	Job/Batch	.	OPT	.	DRP
71	Low	Low	Low		Low	Low	Low	FP	Job/Batch	.	OPT/MRP	.	DRP
72	Low	Low	High		Low	Low	Low	DR	Job	.	OPT	.	DRP
73	Low	Low	Low		Low	High	High	FV	Job/Batch	.	OPT	.	DRP
74	Low	Low	Low	:	Low	Low	Low	QC	Line/Cont.	. .	JIT	. .	Q,R
75	Low	High	High	:	Low	Low	Low	DR	Job		OPT	. .	DRP

Legend:
A - Ability to provide low costs in a price-sensitive market;
B - Delivery on due date;
C - Dependable delivery promises;
D - Short delivery time;
E - Making fast deliveries;
F - Consistent quality;
G - Accuracy in manufacturing;
H- Conformance to product specifications;
I - Reliable products;
J - High performance products;
K - Product variety;
L - Ability to make rapid changes in product mix;
M- Ability to customize products;
N - Rapid volume changes;
O- Adjusting capacity rapidly.
DR - Delivery Reliability
DS - Delivery Speed
FP - Product Flexibility
FV - Volume Flexibility
QC - Quality-of-Conformance
QD - Quality-of-Design
JIT - Just-in-Time;
MRP - Materials Requirement Planning;
OPT - Optimized Production Technology;
ROP-C - Reorder Point (Continuous);
ROP-P - Reorder Point (Periodic);
Q,R - Continuous Review Systems
DRP - Distribution Requirements Planning

Table 4

Diagnostic Validation of the Proposed KBS

Case No	Case Description	IT applications selected by the KBS	Consultants' response to KBS's recommendation
1	Product manufactured: Laptop computers Manufacturing mode: Batch Distinctive competence: Product variety; meet customer preferences Application area: Capacity Planning and Inventory Management	Capacity Requirements Planning (CRP); Materials Requirements Planning (MRP).	Agreed. Strongly Agreed.
2	Product manufactured: Paper board Manufacturing mode: Continuous plant Distinctive competence: Low price; consistent quality Application area: Demand Management and Distribution system	Make-to-stock demand management system (MTS); Continuous Review distribution system (Q,R).	Strongly Agreed. Agreed.
3	Product manufactured: Machining jobs Manufacturing mode: Job Shop Distinctive competence: Keep delivery promises; ability to change product-mix rapidly Application area: Inventory Management and Shop Floor Control system.	Optimized Production Technology inventory management system (OPT); Sequencing and scheduling shop-floor control system (Seq./Sched.)	Agreed, but might have used MRP as well. Agreed.

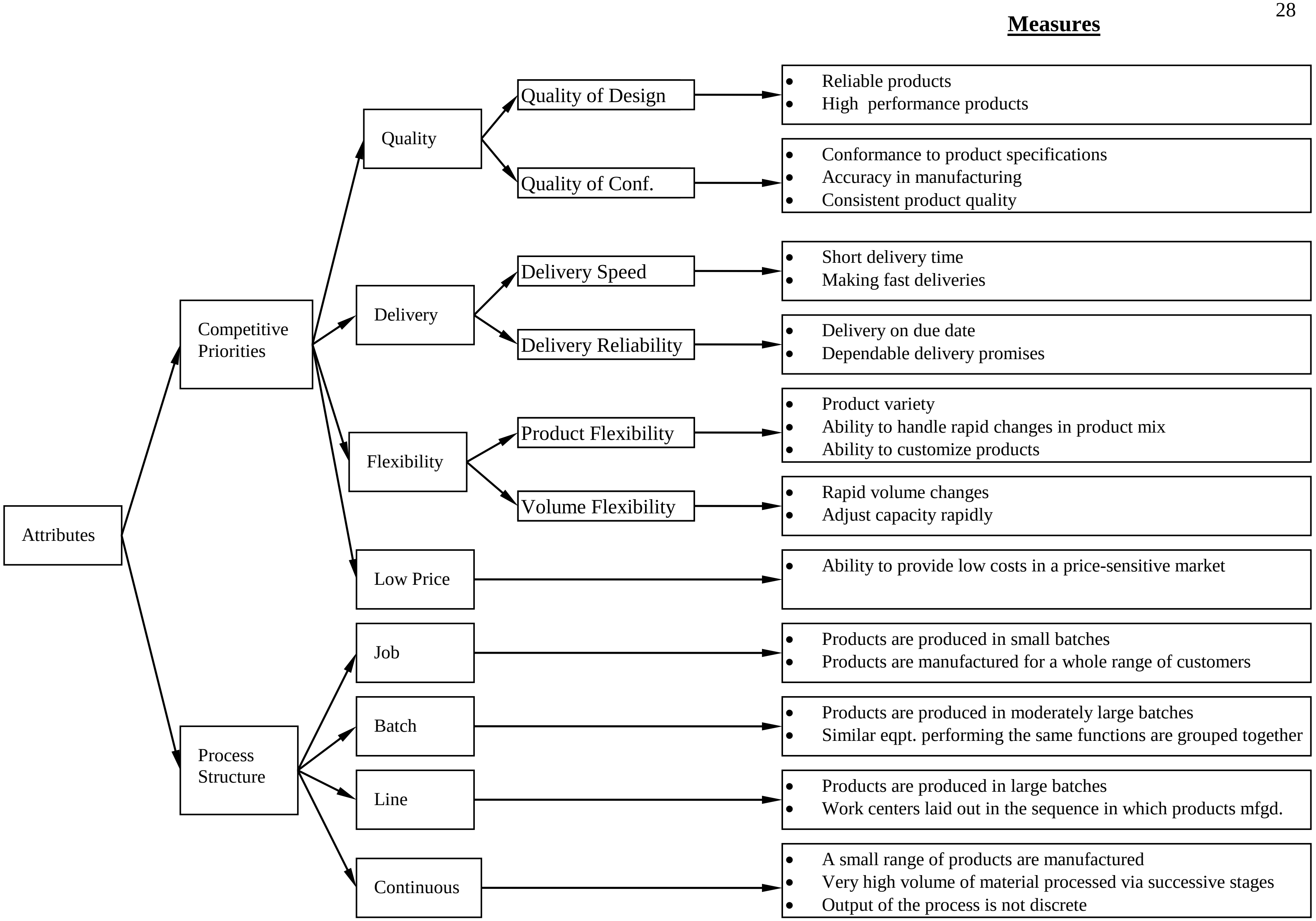

Figure 2. The Attributes Used for Mapping

Figure 3. A Subset of the Induction Rule

APPENDIX 1

ID3 Algorithm

ID3 as proposed by Quinlan [44], is a data-driven approach that develops a rule structure to satisfy a given set of instances or conditions. The algorithm arranges the properties used to generate the inductive rule in an ascending order of entropy (i.e., a measure of uncertainty). This ensures that the properties or characteristics with greater discriminating power are used earlier in the inductive rule. Given a classification of objects into n sets, $c_1,\ldots c_n$, and their probability (based on the number of occurrences), the algorithm derives the entropy E(c) as follows:

$$E(c) = -\sum_{i=1}^{n} p(c_i) \log p(c_i)$$

This produces a ranked set of entropy values, $E(C/A_1) < E(C/A_2) <\ldots < E\,(C/A_n)$, where $A_1\ldots A_n$ are attributes, n is the number of attributes, and $E(C/A_1)$ is selected as the attribute to be used initially.

The ID3 algorithm creates an induction rule that initially considers the problem features that reduce the level of entropy the most. It is possible that some of the attributes may not contribute to the selection process and, thus, be redundant in arriving at certain goals. The resulting induction rule can solve cases not included in the original rule set, i.e., represent a superset of the original case set.