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Ravi Kathuria
Chapman University, kathuria@chapman.edu

Murugan Anandarajan
Drexel University

Magid Igbaria
Claremont Graduate University

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Linking it Applications with Manufacturing Strategy: An Intelligent Decision Support System Approach

Ravi Kathuria
Department of Management & Information Systems
Haub School of Business
Saint Joseph's University
5600 City Avenue, Philadelphia, PA 19131
E-mail: kathuria@sju.edu

Murugan Anandarajan
Department of Management
Drexel University
32nd & Chestnut Streets, Philadelphia, PA 19104
E-mail: anandara@erols.com

Magid Igbaria
Information Science
Claremont Graduate University
130 East Ninth Street
Claremont, CA 91711
E-mail: magid.igbaria@cgu.edu

And
Faculty of Management
Tel Aviv University
Tel Aviv 69978
ISRAEL

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ABSTRACT

Research has indicated the importance of matching Information Technology (IT) applications or manufacturing systems with the competitive strategy of a company. 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 developed an Intelligent Decision Support System (IDSS) that would assist managers with: assessment of the relative importance of competitive priorities in their organization, evaluation of the fit between the competitive priorities and their dominant process structure, and identification of the IT applications that are consistent with both the competitive priorities and the process structure. The IDSS is comprised of an interactive user interface, a knowledge database, a decision model, and a Knowledge-Based System (KBS) that was developed using the 1st class KBS shell. Validation of the system illustrates that its performance is good as the human expert, 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. The choice and use of the right type of IT application should provide a company with a competitive edge.

Subject Areas: Artificial Intelligence; Manufacturing Strategy; MIS/DSS & Computer Systems; Operations and Logistics Management.

LINKING IT APPLICATIONS WITH MANUFACTURING STRATEGY: AN INTELLIGENT DECISION SUPPORT SYSTEM APPROACH

INTRODUCTION

Studies of manufacturing companies indicate that over half their capital expenditures involve some form of IT (Cooper & Zmud, 1990), which has the potential to provide a competitive advantage for these companies (Earl, 1993; Ives & Jarvanpaa, 1991). Researchers have, however, pointed out that the mere introduction of IT itself does not confer competitive advantage, but the choice of IT should stem from an understanding of the business and any desired changes in the business (Grover & Malhotra, 1997; Huff & Beattie, 1985). The need for alignment between the business needs and the characteristics of the IT application has been consistently emphasized in the Information Systems (IS) as well as the Manufacturing Strategy literature (cf., Malone & Rockart, 1991; McFarlan, 1984; Berry & Hill, 1992). This fact has been further highlighted by Cerveny and Scott (1989), among others, who found that not all users of a widely used IT application in manufacturing, the Material Requirements Planning (MRP) systems, had derived the potential benefits of these systems. This has been attributed to the misfit between the manufacturing needs and priorities of the users and the characteristics of the IT application – MRP (Krajewski & Ritzman, 1992).

To avoid the potential misfit described above; many researchers have developed models and frameworks over the years. For instance, Parsons (1983) emphasized the need for alignment of IT applications with the generic strategies—low cost or differentiation of firms. Hayes and Wheelwright (1984) and Skinner (1969,1985) emphasized the importance of aligning systems for manufacturing, planning and control as well as for quality management with the manufacturing strategy of the company. Cooper and Zmud (1990), based on an empirical study, proposed that the choice of IT applications for inventory management should be consistent with the process structure (Job, Batch, Line, Continuous) of a company. Integrating these various concepts, Kathuria and Igbaria (1997) developed an integrated framework (see Table 1) that spans the choice of IT applications in areas ranging from product design through distribution. Their framework suggests that an IT application should be aligned with both the competitive priorities (Cost, Quality, Flexibility, Delivery, etc.) and the process structure of an organization in a manufacturing environment. Figure 1 summarizes the contribution of various studies, including those mentioned above, which suggest some form of alignment between strategy and manufacturing systems or IT applications.

Insert Table 1 and Figure 1 about here

Although Kathuria and Igbaria's (1997) framework is the only fully integrated framework to date, it is restricted in its practical usefulness for the following reasons. First, their framework does not provide any mechanism to identify either the competitive priorities or the process structure of the user. With managers having difficulty in expressing in precise terms what needs to be emphasized or improved (Upton, 1995), the lack of any measure to determine a company's competitive priorities will only further aggravate the problem. Second, if the key manufacturing tasks underlying some competitive priorities are equally served by more than one IT application, the corresponding cell in their framework is left blank, thus offering the user no help with the identification of the right IT application. Third, their framework seems to be based on the assumption that a particular IT application is either suitable or unsuitable (a binary variable) for a given competitive priority-process structure combination. Since different companies place a varying degree of emphasis on competitive priorities (Wheelwright, 1984; Corbett & Wassenhove, 1993), it may have been more useful to rate the suitability of alternative IT applications for any given competitive priority-process structure combination on a Likert scale, ranging from highly incompatible to highly compatible, rather than on a binary scale. Therefore, although the three-dimensional frameworks, such as Kathuria and Igbaria's, do exploit synergies among the three vital components, which lead to alignment, they are also more difficult to utilize since each new dimension introduces complexity to the equation.

To ascertain the complexity of Kathuria & Igbaria's (1997) framework, we provided 20 senior managers with the framework, which is illustrated in Table 1, where the compatible process structures and the recommended IT applications were (left blank, and shaded in Table 1). The managers were also given the choices of IT applications from which they had to choose from, in each functional area. For example, for inventory management, the options given were MRP, Optimized Production Technology (OPT), Just-in-Time (JIT), Reorder Point- Periodic system (ROP-P), Reorder Point- Continuous system (ROP-C). The results indicate that only 40% of the subjects entries were on target overall. A detailed analysis by functional area revealed that the Shop Floor Control had the most right hits (47%), and the Capacity planning the worst, with only 21% being right.

In actuality the IT selection decision process is more complicated than the subjects faced above. In the real world, companies cater to different customer groups with a relatively different emphasis on the competitive priorities for each group. For example, a company may appeal to forty% of its customers because of low price, to twenty% for delivery reliability, and the remaining for quality of conformance and delivery speed. Again, for the last group of customers delivery speed could be extremely important, whereas quality of conformance may be somewhat important. In such a situation, it is almost impossible for an unaided manager to simultaneously consider several competitive priorities with varying relative importance, and find the best possible process structure and the most appropriate IT applications in seven functional areas. This reasoning is consistent with previous research, which has shown that multi-cue decision situations such as the one considered in this study, are inherently difficult for an unaided human decision-maker (Kleinmuntz, 1990).

The purpose of this study therefore, is to propose and develop an Intelligent Decision Support System (IDSS) which would facilitate a manager's decision process in selecting the appropriate IT application. Research has shown that such decision aids have been extremely beneficial to companies, especially in terms of enabling them to respond quicker to changing competitive and market conditions (Jungthirapanich, 1992; Powell, P.L., Hall, M., & Klein, 1992; Price, J. D., Malley, J.C., & Balsmeier, P. 1994)

The rest of this paper is organized as follows. The next section describes the operationalization of the variables and the IDSS development methodology. This is followed by the validation of the system. The paper concludes with implications of the study for managers and directions for future research

RESEARCH METHODOLOGY

Operationalization of Competitive Priorities and Process Structure

The competitive priorities used in the IDSS include Quality, Delivery, Flexibility, and Cost. These attributes were captured using fifteen items designed by Safizadeh, Ritzman, Sharma, and Wood (1996); Wood, Ritzman, and Sharma (1990); Nemetz (1990); Roth and Miller (1990); and Miller and Roth (1994), and Kathuria, Porth, and Joshi (1999). Specifically the instrument asks users to indicate the emphasis placed on each item in their manufacturing unit, on a scale of 1-'Extremely Low' to 5-'Extremely High.' For example, "Indicate the importance given to making fast deliveries in your manufacturing unit." 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" (Reeves & Bednar, 1994). 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 (Juran, 1988). The latter is measured using three items: conformance to product specifications, ensuring accuracy in manufacturing and consistent quality. Two items indicating importance given to "reliable products" and "high performance products" are used to capture the emphasis on *Quality-of-Design*.

Delivery: In manufacturing, this attribute implies that products are delivered quickly, that is *Delivery Speed*; as well as on-time to customers, that is *Delivery Reliability* (Wheelwright, 1984). The emphasis on *Delivery Speed* is measured using two items: short delivery time, and making fast deliveries. Emphasis on *Delivery Reliability* is captured through delivery on due date, and dependable delivery promises.

Flexibility: The two 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 (Hill, 1989). The emphasis on *Product Flexibility* is measured using three items that indicate the importance given to: product variety, ability to make rapid changes in product mix, and the ability to customize products. The emphasis on *Volume Flexibility* is captured using two items: 'rapid volume changes', and 'adjusting capacity rapidly'.

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. Most manufacturing companies use one of the following: Job, Batch, Line, or Continuous. 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, and use more units of similar equipment.

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 that are not discrete.

This attribute was ascertained using set of nine items, adapted from Safizadeh et al. (1996), and Hill (1994). Users were required to indicate whether a given item described the dominant process structure of their manufacturing unit. A binary scale was used, where 1 is Yes, and 0 is No. For example, Check (1-YES, 0-NO) if the following item comes closest to characterizing your dominant process structure: (a) Products are manufactured in small batches, (b) Products are manufactured for a whole range of customers, (c) Etc.

Validation of the Competitive Priorities and Process Structure Scales

Thirteen of the fifteen items used to operationalize competitive priorities have been used before in several studies mentioned above. In those studies, involving the use of competitive priorities in the manufacturing strategy area, the items loaded on the factors, competitive priorities, as expected. To further test the validity and reliability of these scales, a group of 60 Operations Management students in a university in the Northeast United States, were asked to map the items to competitive priorities and process structures. The mapping data was analyzed using frequency analysis for each item, and by calculating the data ‘mode,’ which is a value in the data set that appears most frequently. The results indicate that the mode for all of the fifteen items that were used to measure competitive priorities was exactly the same as expected. Furthermore, over half the items were mapped correctly by 85-95% percent of the respondents, twenty percent of the items were mapped correctly by 75-84% of the respondents, and twenty percent by 60-74% of the respondents. The scales that had ill-specified items were Product Flexibility and Quality-of-Conformance.

The data mode for eight of the nine items used to operationalize the process structure was as expected. The frequency analysis for the process structure scales revealed that about eighty percent of the items, were mapped correctly by 70-80% of the respondents, and the remaining twenty percent of the items were classified correctly by about 50% of the respondents. The above results, though different from the traditional validity and reliability methods used, provide support for the use of specified items to measure the competitive priorities and the process structure of a manufacturing organization.

Development of the Intelligent Decision Support System (IDSS)

An IDSS can be defined as "a computer-based information system that provides knowledge using analytical decision models, and providing access to data and knowledge bases to support effective decision making in complex problem domains" (Klein & Methlie, 1995). Therefore, the basic idea which characterizes and underlies the conceptual framework of an IDSS is the combination of the capabilities provided by the classical DSS approach, (access to data and information and application of analytical decision models) with those of the Knowledge-based systems (KBS) technology (inferencing and explanation capabilities). KBSs are basically systems that embody the knowledge of experts, and manipulate this expertise to solve problems at an expert level of performance (Rauch-Hindin, 1988). These systems have the ability to encode and manipulate expert knowledge through inference paradigms to intelligently produce expert diagnosis (Zahedi, 1994). Thus, the KBS component receives inputs from the database as well as the users, evaluates them, and provides recommendations to users. (For a detailed description on the benefits of the IDSS approach, see Turban & Watkins, 1986).

The knowledge base component of the IDSS was developed using an artificial intelligence software called 1st class version 5.0. The database, and model base were created using Excel 7.0, while the user interface was based on a graphical user interface design, with dialog boxes, that guided the user through the series of questions. The modular structure of the

IDSS is illustrated in Figure 3. The following sections describe the major components of the system.

Insert Figure 3 about here

IDSS database

We created a database of the experts' knowledge in Table 2 which presents all possible competitive priority-process structure combinations with compatibility rated on a scale of 1 to 5, where 1 is highly incompatible and 5 is highly compatible. Similarly, alternative IT applications under various functional areas are rated for their compatibility with a given competitive priority - process structure combination. For example, in Table 2, Low Price, a competitive priority, is highly compatible (score=5) with Line and Continuous type of process structures, whereas Product Flexibility is most compatible (score=5) with Job and Batch shops. Next, for a Low Price priority pursued with a Line structure, the most compatible Inventory Management system (or IT application) would be JIT, and for pursuing Product Flexibility, in a job shop setting, both MRP and OPT are considered highly compatible.

Insert Table 2 about here

The compatibility scores in Table 2 were determined using a pseudo-Delphi approach. A team of two experts - a POM professor and a manufacturing consultant - was provided with the works of Berry and Hill (1992), Hayes and Wheelwright (1979), Hill (1989), Kathuria and Igbaria (1997), and Kotha and Orne (1989). Each member of the team was first asked to rate the compatibility between competitive priorities and process structures. At the end of the first round, members were provided with the averaged responses and asked to reassess the competitive priority-process structure compatibility. After the second round, the responses were again averaged. In the third round, members were brought together to resolve the differences face-to-face and round off the average scores to the nearest integer. These scores are presented in the third column, 'compatibility with C.P', in Table 2. The same procedure was repeated for assessing the compatibility between various IT applications and priority-structure combinations. Since the number of combinations to be evaluated was very large (560), it took several rounds before the team members sat face-to-face to decide the final ratings under the seven functional areas presented in Table 2.

Table 3 illustrates the second database, which was used in the IDSS. This contained the characteristics of various IT applications in different manufacturing functions and details regarding their suitability for a given manufacturing task and a process structure. The database, which was adapted from Kathuria and Igbaria (1997), was used to provide the user with the characteristics of the most compatible IT applications identified by the system. Outlining the characteristics of the IT application further helps the users in verifying that the recommended IT application is indeed consistent with their competitive priorities and the dominant process structure.

Inset Table 3 about here

Model Formulation

Since most companies do not emphasize just one priority, but instead indicate multiple priorities with varying degrees of emphasis (Ferdows & De Meyer, 1990), a company cannot directly identify the IT applications most suitable to IT perusing Table 2. Therefore, the model base factors in the relative emphasis placed on various competitive priorities, compares the fit between competitive priorities and process structure, and finally evaluates the compatibility of alternative IT applications based on experts' knowledge stored in a database created from Table 2.

Step 1. Determine Relative Importance of Competitive Priorities for a company

a. Based on user input of the relative emphasis placed on fifteen items listed in Figure 1, the system calculates an Average Competitive Priority Score (ACPS) for each of the j competitive priorities for a given manufacturing company k, as shown below:

$$ACPS_{jk} = \frac{\sum_{i=1}^{N} I_{jk}}{N} \qquad \forall j = \text{Low Price, Flex\_ Product, } \ldots, \text{ QD}$$

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where: I_{ik} = emphasis on i_{th} item by k_{th} manufacturing company.

N = number of items used to operationalize j_{th} priority.

b. The system calculates Relative Importance (RI) or weight for each of the j competitive priorities for the manufacturing company k:

$$RI_{jk} = \frac{ACPS_{jk}}{\sum_{j=1}^{7} ACPS_{jk}} \qquad \forall j = \text{Low Price, Flex\_ Product, } \ldots, \text{ QD}$$

Step 2. Determine User Company's Dominant Process Structure

Based on user input of the characteristics of their dominant processes, the system identifies the dominant process structure (DP) for the manufacturing company k by

a. Calculating average score for each of the p process structures:

$$DP_{pk} = \frac{\sum_{m=1}^{M} Q_{mk}}{M} \qquad \forall p = \text{Job shop, ..., Continuous}$$

where: Q_{mk} = Closeness of m_{th} item in characterizing the process structure of k_{th} manufacturing company.

M = number of items used to characterize p_{th} process structure.

b. Selecting a dominant process structure based on the highest DP_{pk}.

Step 3. Evaluate the Fit between Competitive Priorities and Process Structure

a. Based on the Relative Importance (RI) of competitive priorities calculated for a manufacturing company k in Step 1, and their compatibility with different process structures based on our theoretical model in Table 3, the system determines suitability of four process structures by calculating a compatibility-index (CP_PS) as given below:

$$CP\_PS_{pk} \sum_{j=1}^{7} RI_{jk} * CR_{jp} \qquad \forall p = \text{Job shop, ..., Continuous}$$

where: CR_{jp} =Compatibility score between j_{th} competitive priority and p_{th} process structure.

b. Rank order process structures in decreasing order of CP_PS index calculated above.

c. Compare the top ranked process structure at (b) with that identified at Step 2. If same, go to Step 4. If not, discard case.

Step 4. Select IT Applications consistent with Competitive Priorities and Process Structure

a. The system calculates Competitive Priority_Process Structure_IT Application (CP_PS_IT) compatibility index for competing IT applications in each of the seven functional areas ranging from Design through to Distribution. The index is calculated based on relative importance of competitive priorities calculated for a manufacturing company k, in Step 1, the compatible Process Structure identified in Step 3, and the corresponding compatibility score of IT applications from Table 2.

$$CP\_PS\_IT_{tupk} \sum_{j=1}^{7} RI_{jk} * IT_{jtup}$$

$\forall_t$ = competing IT applications in a given functional area u

$\forall_u$ = Design,..., Distribution.

where: IT_{jtup} = Compatibility score between j_{th} competitive priority, t_{th} IT application in u_{th} functional area, given p_{th} process structure.

b. The compatibility indices for alternative IT applications in each functional area are compared, and the ones with the highest index in each area are selected.

In summary, competitive priorities of an organization are ascertained using the importance attached to a list of 15 items that operationalize the first set of (four) attributes, as explained in Step 1 of model formulation under the IDSS development section. Next, the dominant process structure of the company is identified using the fifth attribute (a set of nine items), as in Step 2. The process structure is then matched with the competitive priorities for compatibility. If there is a good fit between the priorities and the process structure, an appropriate IT application, based on the theoretical model in Table 2, is identified in each of the seven functional areas.

The KBS Component

The KBS component of the system deals with modeling the domain knowledge (i.e., user input and alignment information), inferencing and provision of explanations. The KBS component was developed using 1st class, a rule based induction-based shell. See Zahedi (1994) for an in-depth discussion on 1st class.

Using various emphases on the items used to opertionalize competitive priorities and process structures, 70 examples (see Table 4) were developed and were subsequently loaded into the system's knowledge base as inputs. These inputs were run through the model base to provide the outcome that is, the IT application which provided the best alignment with a company's competitive priorities and its process structure. These outputs were loaded into the system's knowledge base as well. The inputs, the process, and the outputs of the IDSS are described in Appendix A for the case scenario #70. Using 1st class's inference engine capabilities induction rules of the decision process were generated. The root of the induction process is the algorithm that is used to induce the rules from the cases (Turban, 1990). The induction algorithm used in 1st class KBS shell is ID3 (Quinlan, 1984) which has been applied extensively to problems with deterministic data. These induction rules facilitate selection of IT applications for new scenarios introduced to the IDSS through the user interface by the IDSS users. The advantage of this intelligent module of the system is that it optimizes the number of questions it asks the user in determining the appropriate IT application.

Insert Table 4 About Here

VALIDATION OF THE IDSS

The IDSS developed in this study is an intellectual construct designed to approximate a selected aspect of reality. It is this basic fact of approximation that raises the issue of validation (Miser, 1993). Failure to view validation within an overall framework can lead to users having a dangerous system. Therefore, the need for an understandable and usable validation methodology is important. In this study, we define validation as the process of checking the extent to which the IDSS developed to allow experimentation on a surrogate world is appropriate to the task in hand. This includes its use in the real-world situations, and is thus a wider form of validity than simply model validity.

The IDSS is validated using the framework proposed by Finlay and Wilson (1997). This framework was developed after an exhaustive review of the validation literature in which over 50 different types of validity were examined. Specifically, the framework examines the validity of the model base, data base, system interface as well as general validity. Each of the validity is discussed below:

Validity of the model base: This was conducted in two stages. First the overall theoretical validity was examined. This included the validation of whether the theoretical underpinnings of the models were sound. The translation of the conceptual model into mathematical formulas (given in steps 1-4) was examined as well. In addition, the analytical validity of the model was confirmed by examining the logic of the models.

Validity of the databases: This validity is concerned with both the precision and accuracy of the input data and with the theoretical aspects of the data models. The input data values were checked for errors. The content validity of the data model focuses on determining which questions used by the IDSS are critical for solving the problem at hand. This process involves comparing the inputs used by the IDSS with those required by a group of experts. In other words, this validation method examines whether the system collects all the appropriate data and excludes all the inappropriate data, as the way that human experts do. To test the content validity, the experts were asked the inputs which were most important to they're decision-making process. If the level of inter-expert agreement was above a 50% cut-off point, the variables were compared to the induction tree of the KBS. The content validity was found to be 82%.

User Interface Validity: Given that there is no compulsion for the system to be used, the primary test of usability is the client's willingness to use the system. A secondary test is that the user understands what is asked from them.

The user interface of the IDSS was evaluated by two user groups, namely 23 mangers and two experts in the field of Production and Operations Management. Both groups were provided with questionnaires to provide feedback about validity of the user interface. Three factors—*ease of use*, *timeliness,* and *usability*-which typically affect the merit of the interface, were evaluated. Each of the factors was evaluated on a scale of 1-5, where 1= extremely low/very unacceptable and 5= extremely high/ very acceptable. Ease of use obtained a score of 4.5, while timeliness and usability scored 4.57 and 4.15 respectively. The results of the evaluation showed that both groups evaluated the IDSS at higher than average acceptable level.

General Validity of the IDSS: This was examined in terms of the structural validity of the system as a whole and experimental validity. The structural validity of the IDSS was conducted in two phases. First the output of the system was compared with the Kathuria and Igbaria (1997) framework to ensure that the IDSS model did not violate any of the relationships. In addition, the model was tested and performed well under extreme conditions, and when presented with conflicting scenarios—when input were inconsistent. For instance, if the systems asked a user the question "Products are manufactured for a whole range of customers," and the user responded "yes," the system should not follow up with the question such as "A small range of products are manufactured." This would indicate a conflicting scenario.

Next, the experimental validity of the IDSS was tested with three manufacturing consultants who had recently conducted assignments related to the selection of IT applications in the following areas: 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, covered by agreements between their employer consulting firms and the client organizations, requested anonymity and declined to divulge any proprietary information. They, however, agreed to summarize relevant information from their projects, which is included in Appendix B.

The consultants were asked to evaluate whether the IDSS recommendations were in line with what they themselves had developed and implemented for their clients. From our conversation with the consultants, we gathered that it was not easy for them to identify the distinctive competence of the client organizations, since managers at different levels (general and manufacturing) and in different functions (manufacturing and marketing) had different views about their core competencies. We found this to be consistent with the literature, which shows lack of agreement between managers about their competitive priorities, among other things (cf., Swamidass, 1986; Kathuria, Porth, & Joshi, 1999). When presented with our user interface (questions asked the user) to elicit competitive priorities and the dominant process structure, the consultants considered it to be a real time-saving device.

Further, the consultants believed that reaching an agreement on the competitive priorities of the client organization would be further complicated by the fact that different customer groups were perceived to have different expectations from the same manufacturer. The proposed IDSS handles this issue by allowing the users to rate fifteen competitive priority items (max) on a scale of 1 to 5, with the possibility of multiple items receiving a common rating, say 5. Similarly, it uses a maximum of nine items to determine the dominant process structure.

Furthermore, the IDSS responses matched closely to the recommendations and decisions of the consultants. To examine robustness, each consultant tested the IDSS with different scenarios they had used in the past experience, but declined to share that information with us for reasons already stated above. The consultants agreed that the IDSS was a good tool for identifying IT applications consistent with the competitive priorities as well as the process structures of manufacturing companies. One consultant noted that his clients may still need him to customize and implement the proposed IT applications.

DISCUSSION AND LIMITATIONS

Research has indicated the importance of matching IT applications or manufacturing systems with the competitive strategy of each company. Few theoretical frameworks have been proposed to help managers align IT applications with their competitive priorities and the dominant process structure. A critical examination of the theoretical frameworks reveals that managers find it difficult to use these frameworks for the following reasons: (i) 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, (ii) frameworks recommend IT applications for a specific competitive priority-process structure combination. Given that companies place a varying degree of emphasis on competitive priorities, the manager placing a relatively high emphasis on two or more priorities would face a highly complex decision-making problem.

We further ascertained the complexity of this decision by asking twenty managers to select appropriate IT applications using Kathuria and Igbaria's (1997) framework, the only fully integrated framework available to date. We found that only 40% of the subjects entries were on target, which was consistent with research that states that multi-cue decision types are inherently difficult for an unaided human decision-maker (Kleinmuntz, 1990). With this in mind, we developed an IDSS that would assist managers in selecting appropriate IT applications. The IDSS, which was extensively validated has the ability to rapidly recommend the most suitable IT applications in each of the seven functional areas ranging from product design through to product distribution. The system, then, extracts the characteristics of the recommended IT applications, and the underlying reasoning for recommending those IT applications from a database.

Typically, managers at different levels (general and manufacturing) and in different functions (manufacturing and marketing) have different views about their core competencies. This is consistent with the literature, which shows lack of agreement between managers about their competitive priorities. Moreover, reaching an agreement on the competitive priorities of the user organization is further complicated by the fact that different managers perceive various customer groups to have different expectations from the same manufacturer. In today's business environment, decisions such as these have to be from an integrated perspective, that is, the decision should be made with the consensus of all managers concerned. A system, such as the one proposed in this study, should facilitate group decision making. If multiple users' inputs lead to different sets of priorities and process structures, it would generate discussion among the users, which should lead to consensus.

In such a manner, this system will facilitate effective decision-making in selecting appropriate IT applications that best match an organization's manufacturing strategy. The IDSS 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 IDSS in a timely, cost effective manner. It may, however, be noted that since the competitive priorities, process structures, and IT applications considered in the paper are all dynamic in nature, it could be argued that the IDSS would have limited usefulness in the future. This issue is further examined below.

First, the competitive priorities of an organization could change over time, and also new competitive priorities, not included in the paper, may become available. When the competitive priorities shift over time, the IDSS could be used to reevaluate the fit between the newly emphasized competitive priorities, the process structure, and the existing IT applications. Depending upon the degree of misfit introduced by the shift in competitive priorities, the organization might want to consider investing in new IT applications, as proposed by the IDSS. In the second case, as new competitive priorities – not covered in the model base of the IDSS – evolve, the model base of the IDSS may have to be updated to include those new competitive priorities.

Second, the model base of the proposed IDSS does not include flexible or off-diagonal process structures (also classified as ‘Concurrent Technologies’ by Kim & Lee, 1993). It rather focuses on the more traditional process structures, Job shop through Continuous. This paper being the first ever attempt on developing an IDSS to align the three vital elements – competitive priorities, process structures, and IT applications – has the above limitation, which could be addressed in a future version of the IDSS. It is acknowledged that as the off-diagonal incidences of the product-process matrix increase, the value of the proposed IDSS may have to be reexamined as new structural or infrastructural elements may become relevant in selecting appropriate IT applications. Our contention, however, is that despite the introduction of flexible manufacturing systems, the organizations would still maintain one of the four basic process structures. For example, in a line setup, the infusion of IT and other advanced manufacturing technologies might make it possible to easily switch from one product to another. As a result, an organization might decide to have one or two mixed-mode assembly lines instead of several dedicated lines, but the underlying structure of the organization would still remain a line structure. If so, the proposed IDSS would not lose its relevance. Furthermore, the continuous process structures would remain continuous due to the nature of products, such as sugar, fertilizer, etc., manufactured in those plants despite the infusion of IT. Similarly, Job shops could introduce more NC or CNC machines, but due their nature of business would remain Job shops, that is those catering to a diverse set of customers.

Third, in the contemporary dynamic environment of information technology many "generalized software" tools (IT applications) are appearing in the market place. These tools are considered universal and the same tool could be applied and implemented differently in different contexts. If so, the contribution of the proposed IDSS could be questioned since the issue of alignment between these IT applications and competitive priorities/process structure combinations might cease to exist. Although such universal IT applications do exist, their flexible nature may not suit the requirements of all organizations. IT flexibility is attained at the cost of subtle specialties and "bolt-ons" that may be required by different organizations. Many such applications need to be reconfigured to meet the needs of an organization. Such reconfigurations take time and are expensive. Further, the reconfiguration is basically done to achieve some kind of a fit, in this case the fit between the IT application capabilities, competitive priorities and the process structure of an organization.

Another related issue is the extent of IT component in some of the IT applications considered in this paper, which could be minimal at the present time. But, such was the case with MRP in the seventies when it was first implemented. Over the years, the IT component has tremendously increased in inventory management applications. We expect this trend to continue with other functional areas. This system and the underlying framework considered IT applications in seven functional areas of manufacturing. A logical extension of this paper would be to include other areas, such as maintenance and reliability, purchasing, human resources management, finance, accounting and marketing. The system can also be extended to non-manufacturing units (especially, service organizations). This can be achieved by identifying competitive priorities typically pursued by such organizations; categorizing service operations on dimensions like degree of customer contact, degree of automation or labor intensity, etc.; and relating these categories with specific competitive priorities as well as IT applications.

Given the intricate nature of the present study and the enormous time commitment expected from the experts, we could not get more than two experts to create the knowledge base of the IDSS using the pseudo-Delphi approach. We however, acknowledge this as a limitation of the study. Also, the scales used to operationalize competitive priorities and process structures need to be further validated with data from manufacturing organizations. This study used working professionals that are currently enrolled in a business education program. Furthermore, the IDSS should be used in an advisory capacity and its recommendations may need to be fine-tuned since the senior management may, at times, have priorities that may override logic, which is true with any advice, or expert or intelligent system.

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Table 1: Competitive Priorities, Compatible Process Structures, and Corresponding IT Applications**

Competitive Priority	Compatibility with Process Structure: Job ... Continuous	Design	Demand Mgt.	Capacity Planning	Inventory Mgt.	Shop Floor	Quality Mgt.	Distrib--ution
		Corresponding IT Applications by Functional Area						
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.

** Adapted from Kathuria & Igbaria (1997).

<u>Legend</u>:

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.

Table 3: IT Applications-Characteristics and Suitability for Manufacturing Task/Process Structure

Manufacturing Function and IT Applications	Characteristics and Suitability for Manufacturing Task / Process Structure
Product Design: Computer-Aided Design (CAD)	Helps designer to consider a large number and variety of design alternatives; Helps create a manufacturing data base; Improves quality of design; Works best with high product variety and multitude of components (Groover, 1987).
Design For Manufacturability (DFM)	Helps designer to focus on easy-to-build designs, which take less time to manufacture on the plant floor; Helps designer to focus on the economic aspects of the product; Helps designer to keep track of the amount of cost they have designed in so far; best suited for industries where product life cycles are short (Wallace, 1992).
Demand Management:	
Make-to-Stock Demand Management (MTS)	Demand is forecasted; Few actual customer orders, more forecasts; Customer needs met by providing adequate finished goods inventory; Maintain desired customer service level; Product mix ratios remain fairly constant; Uncertainty due to demand variations around the forecast (Vollman, Berry, & Whybark, 1992).
Assemble-to-Order Demand Management (ATO)	Orders booked for several periods into the future; Available-to-promise concept applied in booking customer orders; Making accurate promise dates to customers; Uncertainty of quantity and timing of customer orders and product mix (Vollman et al., 1992).
Make-to-Order Demand Management (MTO)	Orders not completely specified when booked; Products take several months to manufacture; Track orders through all phases of plant activity;Control customer orders to meet delivery dates; set promise dates (Vollman et al., 1992).
Capacity Planning:	
a) Rough-Cut Capacity Planning:	
(i) Capacity Planning Using Overall Factors (CPOF)	Minimal differences in capacity requirements for various products; Similar products; Less variety (Vollman et al., 1992).
(ii) Capacity Bills Procedure (CBP)	Products have different capacity requirements; High variety; Dissimilar products (Vollman, Berry, & Whybark, 1992).
(iii) Resource Profiles (RP)	Done by work centers; Suitable for job shops or low volume batch systems (Vollman et al., 1992).
b) Capacity Requirements Planning (CRP)	Best suited for complex product structures that require detailed material planning and release of work orders for shop scheduling; High product variety or broad product line (Vollman et al., 1992).
Inventory Management:	
Materials Requirement Planning (MRP)	For firms that produce in batches, low to medium volumes; offer a number of product options (Cerveny & Scott, 1989; Krajewski & Ritzman, 1992; Baudin, 1990).
Just-in-Time (JIT)	More of a philosophy than just another computerized planning system; For repetitive environment, stable schedule; Narrow product range; Standard items (Krajewski & Ritzman, 1992; Krajewski, King, Ritzman, & Wong, 1987; Monden, 1981).

Table 3 continued: IT Applications-Characteristics and Suitability for Manufacturing Task/Process Structure

Manufacturing Function and IT Applications	Characteristics and Suitability for Manufacturing Task / Process Structure
Optimized Production Technology (OPT)	For nonrepetitive environment, particularly job shops; Varied products, multitude of components; Concentrates on bottlenecks and prioritizes allocation of resources accordingly; emphasis on building what is required for the market when it is required (Ptak, 1991; Goldratt & Cox, 1984)
Reorder Point (ROP)	
-Continuous Review	Works best for non-discrete (continuous) item manufacturing, few BOM levels, small lot sizes (Buffa & Miller, 1979).
- Periodic Review	Demand is known; Less safety stock (Low inventory) (Buffa & Miller, 1979).
Shop Floor Systems:	
Assembly Line Balancing (ALB)	For high volume, fixed routing, systems; Standard products. Leads to best possible utilization of resources with highest possible rate of output (Stevenson, 1993; Buffa & Miller, 1979).
Sequencing / Scheduling (Seq./Sched.)	For small batch, low unit volume systems, wide variety of products. The objectives could be: minimizing job completion time or shop congestion, minimizing maximum job tardiness, etc. (Stevenson, 1993; Buffa & Miller, 1979).
Quality Management:	
Quality Planning (QP)	Identify customers, discover customer needs, develop product and process features, establish quality goals; Achieve quality characteristics desired by customers (Juran & Gryna, 1993).
Quality Control (QC)	Making sure that products are made to standards; Intermediate (Batch)/ continuous systems (Juran & Gryna, 1993).
Quality Engineering (Taguchi Methods) (QE)	Linking/optimizing product design and manufacturing processes; Control at design stage through parameter design rather than tolerance design; Eliminates the need for process control; Emphasis on optimizing at the design stage through the use of low cost material and components (Barker, 1986; Pignatiello, Jr., 1988; Byrne & Taguchi, 1987).
Quality Function Deployment (QFD)	Primary impact on product features and performance; Get customer requirements embedded in the product; Performance quality as opposed to conformance- to-requirements quality (Wallace, 1992; Day, 1993; Akao, 1990).
Distribution:	
Distribution Requirements Planning (DRP)	When forecasts vary from period to period; More forecasts than actual orders; High variety, large number of end-items (Wallace, 1992; Turner, 1990; Bregman, 1990)
Q, R Continuous Review System (Q, R)	Constant requirement assumption; narrow product range; continuous review. (Krajewski & Ritzman, 1992; Buffa & Miller, 1979).

(Adapted from Kathuria & Igbaria, 1997).

Table 4: Simulated Case Scenarios (Examples)

Case #	Competitive Priority Measures					Process Structure Measures			Compatible IT Applications			
	A	C	. . .	N	O	P	. . .	X	. .	Inventory	. . .	Distribution
1	1	1	. . .	5	5	1	. . .	0	. .	OPT/MRP	. . .	DRP
2	5	1	. . .	1	1	0	. . .	0	. .	JIT/ROP-C	. . .	Q,R
3	1	1	. . .	1	1	1	. . .	0	. .	OPT/MRP	. .	DRP
4	1	1	. . .	1	1	1	. . .	0	. .	OPT/MRP	. . .	DRP
5	1	1	. . .	1	1	1	. . .	0	. .	OPT	. . .	DRP
6	1	1	.	5	1	1	.	0	. .	OPT/MRP	.	DRP
7	1	1	.	1	1	1	.	0	. .	OPT	.	DRP
8	1	1	.	1	1	0	.	1	.	ROP-P	.	Q,R
9	1	1	.	1	1	1	.	0	.	OPT/MRP	.	DRP
10	1	1		1	1	0		1	.	ROP-P	.	Q,R
11	1	5		1	1	1		0	.	OPT	.	DRP
12	1	1		5	1	1		0	.	OPT	.	DRP
13	1	1		1	1	1		0	.	OPT/MRP	.	DRP
14	1	1		1	1	1		0	.	OPT/MRP	.	DRP
15	3	1		1	1	0		1	.	JIT/ROP-C	.	Q,R
16	1	5		1	1	1		0	.	OPT	.	DRP
17	1	1		1	1	0		1	.	JIT	.	Q,R
18	1	1		3	5	1		0	.	OPT	.	DRP
19	1	1		1	1	1		0	.	OPT/MRP	.	DRP
:	:	:	:	:	:	:	:		:	:	:	:
:	:	:	:	:	:	:	:		:	:	:	:
61	1	1	:	5	1	1	:	0	.	OPT/MRP	.	DRP
62	1	1		1	1	1		0	.	OPT	.	DRP
63	1	1		5	1	1		0	.	OPT/MRP	.	DRP
64	1	1		5	3	1		0	.	OPT/MRP	.	DRP
65	1	1		1	1	1		0	.	OPT	.	DRP
66	1	1	.	1	1	1	.	0	.	OPT/MRP	.	DRP
67	1	1	.	5	3	1	.	0	.	OPT	.	DRP
68	1	1	.	1	1	1	.	0	.	OPT/MRP	.	DRP
69	1	5	.	1	1	1	.	0	.	OPT	.	DRP
70	1	1	. . .	5	5	1	. . .	0	.	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. **P** - Products are produced in small batches
Q - Products are manufactured for a whole range of customers **R** - Products are produced in moderately large batches
S - Similar equipment performing the same functions are grouped together **T** - Products are produced in large batches
U -Work centers laid out in the sequence in which the products manufactured **V** - A small range of products are manufactured
W-Very high volume of basic material is processed via successive stages **X** - Output of the process mentioned at W is not discrete.

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

FIGURE 1: Literature Linking Competitive Priorities, Process Structure and IT Applications

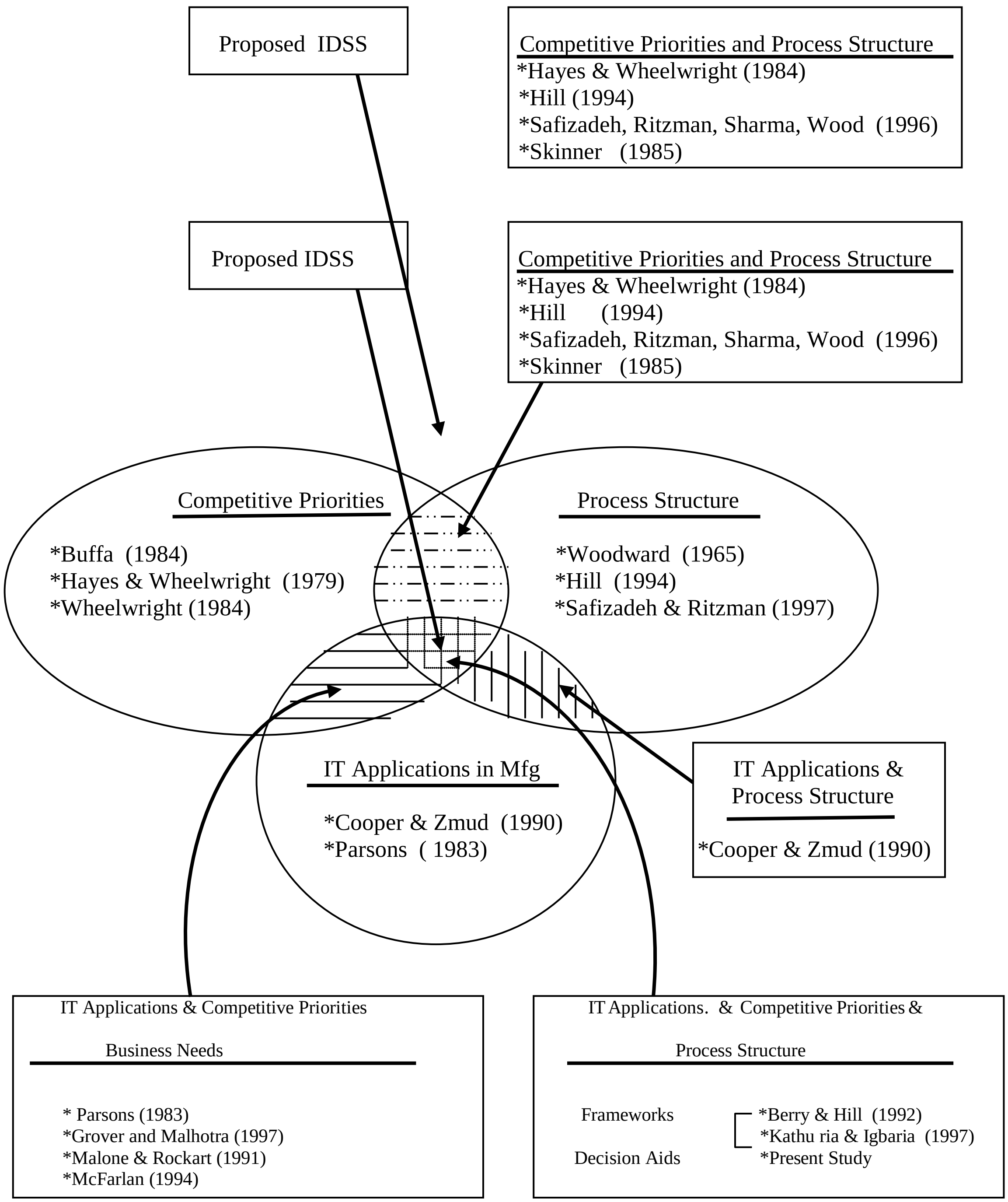
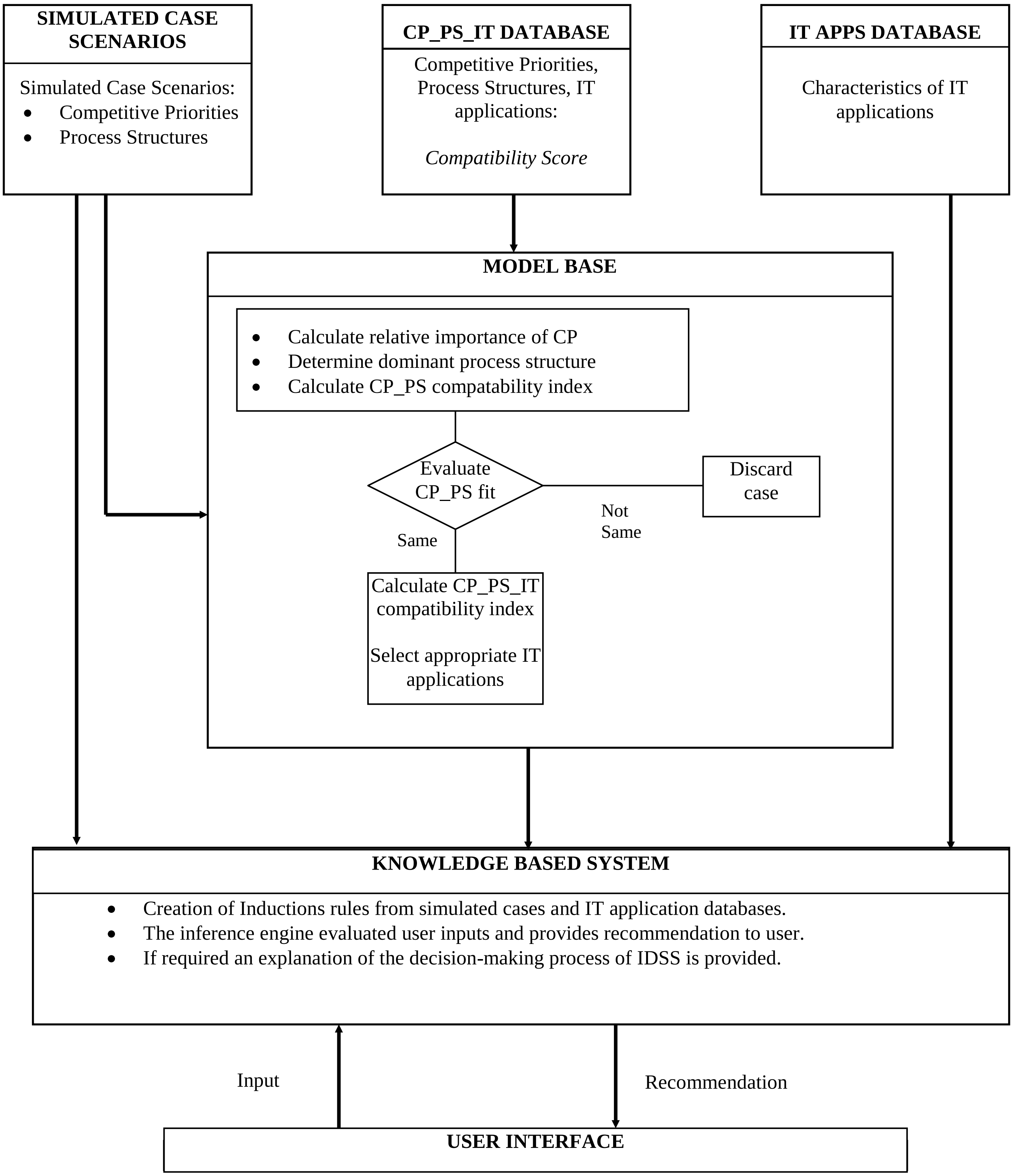


Figure 3: Modular Structure of IDSS



Appendix A

Case Scenario: To illustrate how the IDSS works, we consider a job shop that is in need of identifying an appropriate IT application for inventory management.

The job shop places an extremely high emphasis on product and volume flexibility.

Step 1 (a): **Inputs to determine the Competitive Priorities (CP)** Indicate the importance given to each item based on the Competitive Priorities *(where 1 = Extremely low and 5 = Extremely High)* ***CP Criteria***		User Response	**Step 1 (b): Calculation of Importance of CP**		**Step 1 (c): Calculation of Relative Importance of CP**	
Low Price	Ability to provide low costs in a price-sensitive market.	1		1	(1/13) =	0.0769
Del_Reliablty	Delivery on due date.	1				
Del_Reliablty	Dependable delivery promises.	1	(1+1)/2 =	1	(1/13) =	0.0769
Del_Speed	Short delivery time.	1				
Del_Speed	Making fast deliveries.	1	(1+1)/2 =	1	(1/13) =	0.0769
Qual_Conf.	Consistent quality.	1				
Qual_Conf.	Accuracy in manufacturing.	1				
Qual_Conf.	Conformance to product specifications.	1	(1+1+1)/3 =	1	(1/13) =	0.0769
Qual_Design	Reliable products.	1				
Qual_Design	High performance products.	1	(1+1)/2 =	1	(1/13) =	0.0769
Flex_Product	Product variety.	1				
Flex_Product	Ability to make rapid changes in product mix.	5				
Flex_Product	Ability to customize products.	3	(1+5+3)/3 =	3	(3/13) =	0.2300
Flex_Volume	Rapid volume changes.	5				
Flex_Volume	Adjusting capacity rapidly.	5	(5+5)/2 =	5	(5/13) =	0.3800
			Total	1 3	Total	1.0000

Step 2(a):
Inputs to determine the Process Structure (PS)

Step 2 (b):
Determination of the PS

Which of the following come closest to characterizing your dominant processes:

(where 1=Yes, 0=No)

PS Criteria

PS Criteria	Description	User Response	Determination
Job Shop	Products are produced in small batches	1	
Job Shop	Products are manufactured for a whole range of customers	1	(1+1)/2 = 1
Batch Shop	Products are produced in moderately large batches	0	
Batch Shop	Similar equipment performing the same functions are grouped together	1	(0+1)/2 = 0.5
Line	Products are produced in large batches	0	
Line	Work centers are laid out in the sequence in which the products are manufactured	0	
Line	A small range of products are manufactured	0	(0+0+0)/3 = 0
Continuous Flow	A very high volume of basic material is processed through successive stages- - into one or more products	0	
Continuous Flow	Output of the process, mentioned in the previous question is not discrete	0	(0+0)/2 = 0

Based on the calculations above, the Dominant Process Structure = JobShop

Step 3: Evaluation of the fit between CPs and PS

(a) Based on the information provided in Table 2, and Step 1c, the CP_PS Compatibility Index is calculated for all four process structures as under:

JOB	(.0769*2+. 0769*5+………..+.38*5) =	4.4342
BATCH	(.0769*2+.0769*4+………..+.38*5) =	4.4342
LINE	(.0769*5+. 0769*2+………..+.38*3) =	2.4511
CONTINUOUS	(.0769*5+. 0769*2+………..+.38*2) =	2.4511

(b) The PSs are arranged in decreasing order of CP_PS Compatibility Index:

JOB SHOP/ BATCH SHOP ... LINE/CONTINUOUS

(c) The top ranked PS in Step 3 (b) above, is compared with that identified at Step 2(b). A comparison of the output from STEP 3(b) and STEP 2(b) indicates that the user's existing process structure is same as that identified by the IDSS as compatible with user's intended competitive priorities.

Step 4: Selecting IT applications consistent with CPs and PS
(a) Evaluate CP_PS_IT Compatibility Index
Since the user is interested in an appropriate IT application in Inventory Management, the compatability indexes are calculated for that functional area only, using information from

Step 1 (c), Step 3 (c), and Table 2.

Relative Importance of CPs as calculated in Step 1 (c)		**Process Structure from Step 3 ©**	**Compatibility Score of IT Applications in Inventory Management with CP and PS from Table 2**				
			JIT	**MRP**	**OPT**	**ROP-C**	**ROP-P**
Low Cost	0.0769	Job Shop	1	3	5	2	1
Delivery Reliability	0.0769	Job Shop	1	4	5	1	1
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:
Flexible Volume	0.3800	Job Shop	1	4	5	1	1
CP_PS_IT Compatibility Index **-->**			1.4559	4.0542	4.9725	1.3783	0.9945

(b) Output: The recommended IT application(s)
After comparing the CP_PS_IT Compatibility Indexes for competing IT Applications for the given case, the IDSS selected OPT based on the highest compatibility index.

(c) Output: Characteristics of the recommended IT application(s)
The system fetches the characteristics of the Above IT Application(s) from the database shown in Table 3.
OPT is considered suitable for:
non-repetitive environments, particularly job shops; varied products, multitude of components; concentrates on bottlenecks and prioritizes allocation of resources accordingly; emphasis on building what is required for the market when it is required.

Step 5: Creation of the Induction Rule
Using the inputs and outputs from Steps 1 (a), 2 (a), 3 (c) and 4 (b), the knowledge base of the IDSS is created. This intelligent module helps identify the appropriate IT applications for subsequent users by asking minimal number of questions.

Appendix B

Case Study I: A computer factory in Japan makes over twenty varieties of laptop computers. It tries to distinguish itself from the competition by offering choices that customers want. The company produces in a batch mode that facilitates switching between models. To support the pursuit of offering variety to its customers, the company hired a U.S. based manufacturing consulting firm. Specifically, the company wants to develop an appropriate manufacturing system for capacity planning and inventory management.

Case Study II: A U.S. based paper board manufacturer supplies a limited variety of standardized paper board products to a handful of bulk buyers. The company competes on the basis of low cost and consistent quality. Order after order, it strives to adhere to the design specifications in terms of thickness and other dimensions. The company uses a continuous paper plant to produce the board, which is later cut and finished to form boxes per specifications of few bulk buyers. Facing an upsurge in demand, the company wants to revamp its demand management and distribution system.

Case Study III: A small machine shop caters to the machining needs of several customers. It has a mix of traditional machinery and some computerized numerically controlled (CNC) machines. Over the years, the shop has attracted and retained customers by keeping its delivery promises. To meet the varying needs of its customers, it has the ability to make rapid changes in the product mix. Lately, the shop is experiencing an increase in the inventory of raw materials as well as the shop congestion due to increased work-in-progress. As a result, the company finds it difficult to make deliveries as promised. Realizing the need for a better manufacturing management system, the company is seeking help with the development of an appropriate inventory management and shop floor control system.