PLANNING AND DESIGN OF COMPUTER INTEGRATED MANUFACTURING SYSTEMS USING AN EXPERT SYSTEM

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ABSTRACT

In this research, a methodology for planning and design of CIM systems is developed using an Expert System Shell (AM). The expert system models address various issues of planning and design such as order processing, part information, machine information, handling system information, networks, number of stations or machines, selection of machines, system configuration and other organizational and technical CIM functions. The planning and design models are illustrated through an example.

Keywords: *Planning, design, CIM, AI, expert system shell*

الملخص

تم في هذا البحث تطوير منهجية لتخطيط وتصميم نظام CIM باستخطام طريقة نظام الخبرة. حيث تحتوي نماذج نظام الخبرة على العديد من قضايا التخطيط والتصميم مثل معالجة الطلب والمعلومات المتعلقة بالمنتج والآلة ومناولة المواد والشبكات وتحديد عدد محطات الانتاج واختيار الآلات والشكل العام للنظام وغير ذلك من الوظائف الفنية والتنتظيمية لنظام CIM. كما تم تقديم مثال يوضح النماذج المعدة للتخطيط والتصميم.

1. INTRODUCTION

Manufacturing systems must respond to their rapidly changing marketplace and to the new technologies being produced and used in industry. Nowadays, the problems of manufacturing are more complicated due to many changes occurring not only simultaneously but also more rapidly than in the past. These changes are occurring in all fields of manufacturing systems. These changes include: more complex product, higher quality, increased product liability, more customized products, shorter product life cycle, fewer skilled workers, increased competition, etc. Manufacturing change can be an effective competitive weapon if it is well planned, designed and supported by powerful modeling methods and technologies. Many factors such as reduced lead time, greater flexibility, improved communications and co-ordination with suppliers, increased productivity, improved design and greater manufacturing control can make industrial organizations far more competitive in the future.

Various authors and practitioners have suggested that Computer Integrated Manufacturing (CIM) will improve manufacturing, making it faster and more competitive [Vail, 1988, Guetari and Nguyen, 1997, Pleinevaux, 1997, Al-Ahmari, 2002].

CIM includes all the functional areas of manufacturing organization. Each functional area should be integrated with the others. The major components of CIM are Computer Aided Design (CAD), Computer Aided Process Planning (CAPP), Computer Aided Manufacturing (CAM), Computer-Aided Quality Control (CAQ) and Production Planning and Control (PPC).

CIM is a key to the survival of many industries requiring to remain competitive by producing high quality products at the right time and at acceptable costs, to satisfy the fast changing market [Nicholson, 1991]. CIM is one of the fastest growing fields [Vail, 1988]. It is not a single concept or tool but integration of the elements of the system as a whole. In the CIM system all the technology and strategies are based on the concept of “integration”. CIM is a strategy for economical production by effective utilization of different data resources through computer-based methods. Without any doubt, CIM systems, with their long-term impact, require alignment of business and manufacturing strategy [Guetari and Nguyen, 1997]. The current view of CIM appears to represent a strategic panacea for the organization being studied [Pleinevaux, 1997].

By reviewing the literature, it has been found that the inadequate planning and design of CIM and lack of proper modeling methods and techniques represent the fundamental problems of this advanced philosophy. Lack of proper planning for CIM not only hampers its effectiveness when fully implemented, but also produces inadequate insights into the benefits that can be achieved [Sarkis and Lin, 1994]. Effective organizational plans must exist to achieve the desired business goals. The planning step is important in traditional manufacturing system projects, so due to the higher investment and design complexity of CIM, it is essential to improve the planning aspects of the CIM at the early stages of design. Inadequate planning of CIM strategy causes critical problems in decision-making for CIM development and implementation. A formal CIM plan is one of the factors ranked as important and of significant help to CIM implementation [Fossum and Ettlie, 1990].

Even the most sophisticated methods and techniques for CIM design and analysis are useless unless they are integrated with other supports. Therefore, CIM modeling methods are needed to describe the operations and activities that occur within the growing number of increasingly complex CIM components. Because of this complexity of the task realizing CIM, Artificial Intelligence (AI) approaches are required. Developments in AI have had an important impact on advanced manufacturing systems and computer-based methods.

The objective of this paper is to develop a Knowledge Based Computer Integrated Manufacturing System (KBCIMS) methodology for the planning and design of a CIM system

Top

using production rules and analytical techniques. The production rules help user to arrive at a decision while the analytical methods are employed to optimize and calculate the design parameters. The methodology is developed using expert system software AM.

2. LITERATURE REVIEW

In CIM, there are three important development stages, namely, planning, design and implementation. Powerful modeling methodologies and techniques are requested to achieve the requirements of these development stages. To understand the concept of planning, design and implementation, the question "what are systems planning, design and implementation?" must be answered. This section is concerned with reviewing the previous research that has been carried out in modeling, planning and design of CIM due to the wide research trend in the areas of computer-based systems in manufacturing.

It should be noted that the system modeling, planning and design are inseparable notions. Modeling is used to describe system means; therefore, a model is the analyst's description of a system. A system analysis can be defined as a stage in development cycle in which a problem is examined to understand its requirements without planning the implementation stage [Savolainen et al., 1995].

Most of the published reports focus on the technological aspects at an early stage of the development of CIM [Gunasekaran, 1997]. CIM could not be considered as an integrated manufacturing strategy when the role of the other factors such as organizational activities is ignored. It is generally accepted that CIM aims to achieve an effective integration of the different activities of an organization [Hassard and Forrester, 1997]. Many modeling methodologies, techniques and tools have been used for planning and design of CIM systems. Some of these methods originated from fields outside system analysis e.g. Entity Relationship diagrams (ER), Petri nets and mathematical programming models. Others have been specifically developed for system analysis and modeling such as Integrated Computer Aided Manufacturing (I-CAM) techniques [Brandimate and Cantamessa, 1995]. These modeling methods have different characteristics that are appropriate for system's analysis and design. On the other hand, they have some drawbacks as well.

It is obvious from the reviewed papers that the planning and design of CIM systems have not received much attention due to the absence of the technological specifications of these systems during the design and planning phases and the lack of proper modeling approaches which were based upon the computer-based tools. In addition, one can see that the most existing modeling methods and techniques are concerned with the architectural construction of CIM and the various perceptions of the needs of the enterprise. Also there are many papers that have concentrated on the reference models of CIM and the interrelationships between its different activities in terms of information, material and decision flows.

Top

Many researchers compared the modeling methods against each other [Brandimarte and Cantamessa, 1995, Chadha et al., 1991, Pandya, 1995]. The comparison of CIM modeling methods indicates that no single modeling method meets all modeling requirements of manufacturing system. Some modeling methods do not support the planning and design of manufacturing systems. Others are good functional/structured modeling methods and is easy to learn, understand and use. However, some of the limitations such as lacking decision modeling, time scales and simulation aspects are main drawbacks of a number of these methods.

Most existing modeling methods can only support particular aspects of CIM systems. Many researchers and authors have addressed limitations and problems of current CIM modeling methodologies and techniques. For example, [Brandimarte and Cantamessa, 1995] reported that the current modeling methods do not pay enough attention to many important aspects of CIM systems, which need deep integration of many components and elements. The existing modeling tools and approaches do not satisfy all the requirements of the complex manufacturing systems [Chadha et al., 1991]. A number of modeling methods have been compared and two important points concluded [Aguiar and Weston, 1995]. The first is that no single modeling method provides a complete support for decisions along the integration manufacturing enterprise life cycle. The second is that there are a number of gaps such as lack of a good formalism, which must be filled. It is clear that there is a need for AI modeling methods to support the planning and design of CIM systems.

The only guarantee to successfully modeling and designing CIM systems is to use a modeling methodology which involves and mobilizes all the people concerned, and which takes into account function, information, decision, organization resources, as well as economic, social and human aspects [Doumeingts et al., 1995]. It is evident that the need for an integrated method exists. This integrated method can be created by selecting potentially cognate groupings of modeling methods and techniques to seek a means of extending and unifying them to support different phases of CIM systems analysis and design creating software tools that support CIM systems [Aguiar and Weston, 1995]. Furthermore, there is a need to develop software tool to support CIM system analysis and design. AI approaches are required for designing and planning of CIM systems due to the need to integrate many aspects when modeling the two important stages. Developments in AI have had an important impact on advanced manufacturing systems and computer-based methods.

3. EXPERT SYSTEMS

Expert System (ES) and Knowledge Based Systems (KBS) make decision on the basis of input data in a similar way to human experts, who make decisions on the basis of experience, observation and reasoning. The structure of a KB system can be represented in various ways. The main elements of a KB system are: knowledge base (KB), inference engine, working memory, knowledge acquisition and user interface as shown in the Figure 1.

Top

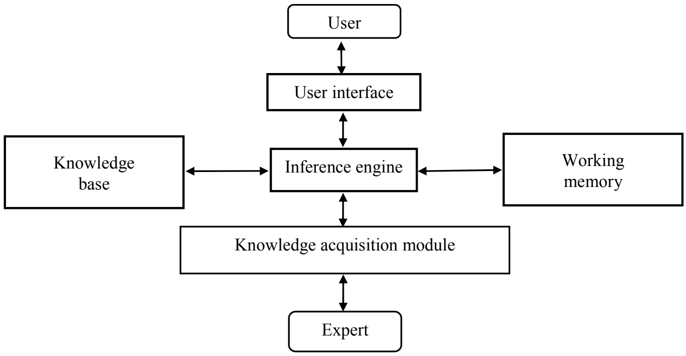

Figure 1. The basic components of a knowledge based system [Kusiak, 1990]

3.1. Applications of Knowledge Based Systems in Manufacturing

The KB systems find applications in several problem areas in science, engineering and manufacturing. The major applications of KB systems are found in manufacturing area. A number of KB system applications in manufacturing have been reviewed [Badiru, 1992, Mital and Anand, 1994]. These applications include:

- Design of Flexible Manufacturing
- Job Shop Scheduling
- Maintenance and Fault Diagnosis
- Material Handling and Supplies
- Robots
- Facilities Layout
- CAD/CAM
- Quality Control

3.2. Selecting A Development Language

The writing of a KB program in any programming language is possible, but certain programming languages are better in executing certain type of programs than others [Owen, 1987]. The major problem in developing KB systems in conventional programming languages is the symbolic manipulation. Conventional languages are mainly used for "number crunching". The languages used to develop ES such as LISP and PROLOG are different from the conventional programming languages in many ways [Badiru, 1992]. For example, AI programming provides a very interactive environment, uses sophisticated procedures, offer recursive processing that is not easily implemented in conventional languages and make use of dynamic memory allocation to adapt to various problem sizes.

Programming with LISP (List Processing) involves defining new functions. LISP is good at list processing and can be used powerfully for heuristic searching and is oriented towards symbolic computation which can conveniently manipulates both symbols and their relationship. The memory management of LISP is efficient because it uses the dynamic allocation of memory space for data storage. LISP's applications include ES, natural language processing, robotics, educational, and psychological programming [Turban, 1995]. The main disadvantage of LISP is that it needs to run on AI specific hardware such as LISP machines.

PROLOG (Programming in Logic) captures the problem solving knowledge in a concise format due to compact mathematical notations. PROLOG is considered as a database of facts and rules. PROLOG can successfully be used in automatic code generation, program verification and design of high level specification languages.

LISP and PROLOG are the most popular and widely used programming languages for AI applications, but the trend of developing KB system applications has slightly been changed since the emergence of ES Shells.

3.3. Expert System Shells

ES Shells are the most widely programming tools used to build KB systems. More than half (56%) the operational systems are developed using Shells, about 23% are developed using AI languages and the remaining are built using conventional languages and tool kits [Edwards, 1990]. Shells are basically derived from the ES by tailoring the different components of the ES to fit in different scenarios. For example EMYCIN or 'empty' MYCIN is a Shell, which is derived from MYCIN, a bacterial infectious, diagnosing ES as reported in [Jackson, 1990, and Singleton, 1991]. The derived Shells are called 'skeletal Shells'. Shells simplify the task of ES, but the usage is restricted to a specific class of problems. The shortcomings of 'skeletal' Shells have led researchers to develop general purpose Shells covering wide range of problems [Jackson, 1990, and Tsai et al., 1993]. Shells are like empty containers in a sense that there is no specific knowledge in the software when it arrives but it certainly provides facilities for programmers to develop KB systems to their particular applications. According to [Jackson, 1990, and Beynon-Davies, 1993] Shells provide a complete pre-programmed environment, which includes knowledge representation schemes, inference mechanism, user interface and explanation facilities.

3.4. Selection of an Expert System Shell

A wide range of commercial ES Shells are presently available in the market and the selection of a Shell has become a bit difficult for the user. Most of the Shells available are PC based. Due to this reason, Shells allow organizations and educational institutions to participate in this relatively new technology. There are many factors in selecting ES Shells, some of which listed by [Badiru, 1992, and Drenth and Morris, 1992] are:

- Knowledge representation: The way the knowledge is represented; whether it is rule based, frames based or other.
- Inferencing: Whether the inferencing method is forward chaining or backward chaining, because different applications require different reasoning strategies.
- Hardware requirement: Whether the hardware meets the requirement of software.
- Cost: Whether the procurement cost of software is reasonable relative to organization's budget and intended use.

The other factors include: justification for the software that will be run by a knowledgeable person, external interfaces with other programs and databases, kind of reports to produce, quality of documentation, ease of learning, ease of use, vendors reputation and product support.

3.5. Application Manager (AM) as a Research Tool

AM is an ES Shell designed by the Intelligent Environment Inc. AM is an advanced version of Crystal. The major difference between the two is the operating system. Crystal is DOS based while AM is window based. AM uses highly interactive interface and includes a wealth of databases and remote system connectivity features to enable users to develop powerful applications easily and quickly. Knowledge is represented as production rules in AM. There are two versions of AM for windows: AM Builder and AM Enterprise. AM Builder is intended for use by a single developer while AM Enterprise is to be used by a team of developers working on an application. The components of an AM application consist of modules, procedures, commands, variables, windows, functions and menus [AM, Intelligent Environment, 1995].

In this research an ES methodology incorporating procedural rules and declarative data is developed for the planning and design of a CIM system. Other conventional problem solving methods such as mathematical programming and simulation are also available to solve the planning and design problem of CIM but the ES systems best suit to solve such a problem due to the well-structured knowledge representation. The user interface facility allows the user to modify and understand how the conclusion or decision is worked out amongst the alternatives. Considering the characteristics and advantages of ES systems, an ES Shell AM has been selected for this research to develop a methodology for the planning and design of CIM.

4. THE DEVELOPED KBCIMS METHODOLOGY

The structure of the KBCIMS methodology for the planning and design of a CIM system is shown in Figure 2. The main elements of the KBCIMS are: user interface, planning model, design model, knowledge base, information base and inference engine. AM uses highly visual interactive interface enabling the user to communicate with the KB system. The planning model comprises a number of modules such as demand information, process plan, machine information, Material Handling System (MHS) information and Local Area Network (LAN) information. The design model contains machine calculations and workload assignment, MHS selection and design parameters calculation, quality control and financial assessment.

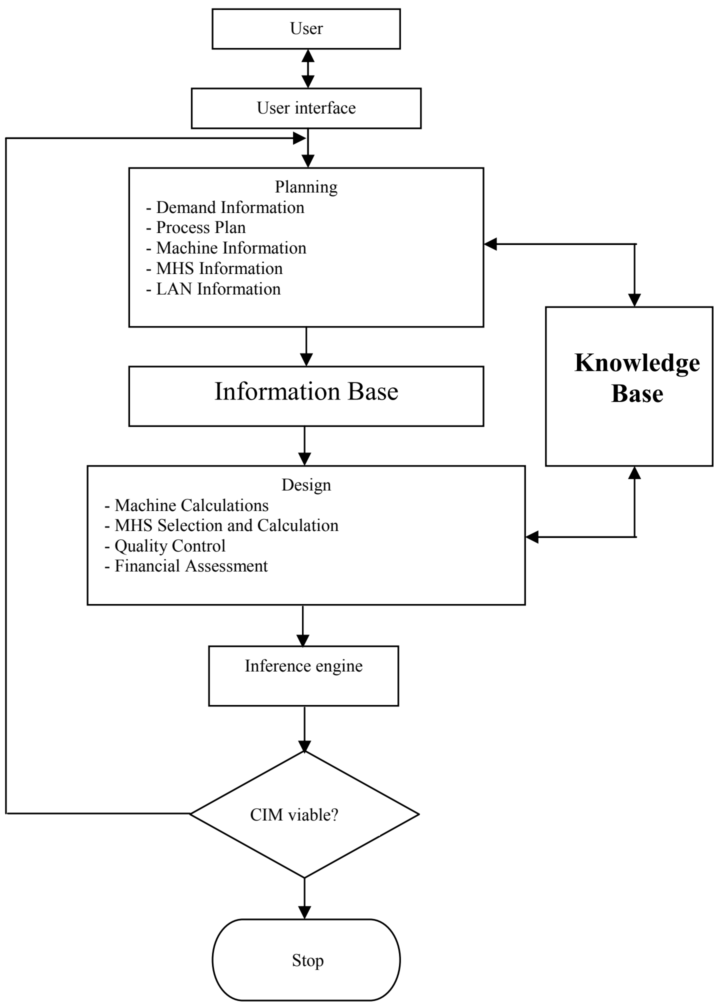

Figure 2. KBCIMS methodology for the planning and design of a CIM system

The knowledge base consists of rules and facts. Knowledge is represented making use of IF, AND, THEN and OR statements. The user's response to the questions is tested with the rules to arrive at a decision. The information base contains all the information (data and text) provided by the user and the result of the user's response to the questions tested with the rules in the knowledge base. Inference engine executes the rules according to the inferencing method (forward chaining/ backward chaining) and control procedure.

The KBCIMS methodology uses forward chaining inferencing strategy. Upon the successful execution of the IF part of the statement, the next statement is then tested. A decision is reached when all the statements are executed successfully. Otherwise, in the case of a failure of a rule, the control jumps to the next alternate set of rules or to the OR statements.

4.1. The Planning Model

The KBCIMS methodology is developed in two stages. The first stage includes the planning issues and requirements. So, a planning model is developed comprising various modules such as demand information, process plan, machine information, MHS information and LAN information. The output of each module is sent to Excel and Information Base. After planning successfully the next stage (the design model) is loaded. A brief description of the planning model is given below.

In the **demand information module**, the KB system asks the user about the number of different part types and the quantity of each part type to be produced by the CIM system. This module accommodates demand forecast for up to five years. The module can also consider the seasonality if there is any. Each year demand is further distributed into months and weeks. The KB system ensures that the demand has been correctly provided (such as use of market surveys, future predictions and competitor analysis). The reason for providing five years demand is to find potential demand for the successful functioning of CIM system.

The KB system acquires detailed information about the parts in the **process plan module**. The information of each part type includes, shapes, weights, geometry (sizes), tolerances, number of processes, number of operations in each process, operation times, nature of operations (sequential or simultaneous or both) and material etc. The KB system also acquires information about the availability of the CIM system per month. In this module maximum of 45 operations are considered on the rotational parts and 36 on the non rotational parts.

In the **machine information module**, a database of the machine tools is developed that includes the dimensions (working area), prices and sizes of the machines. Based on the information in the process plan module, a work envelope is developed for the selection of the machine tools.

Top

In the **MHS module**, the KB system acquires information from the user about the movement, machines, shop floor area etc. The responses of the user are tested with the rules in the knowledge base and a selection of a suitable MHS is thus made. Three types of MHSs are considered in this module (AGVs, conveyors and robots).

The KB system in the **LAN module** acquires information from the user to select a suitable topology (ring network, star network or bus network), access methods (token passing and carrier sensed multiple access with collision detection), communication protocols (MAP: Manufacturing Automation Protocols, MiniMAP, MAP/EPA: Enhanced Performance Architecture) and data transmission medium, (co-axial cable and fiber optics). The KB system arrives at a decision after the responses of the user with the rules in the knowledge base.

4.2. The Design Model

The information from the Information Base is loaded into the second stage, i.e. the design model. This model comprises machines calculations, MHS calculations, Quality control and financial assessment modules. Each of the modules is briefly described below.

In the **machine calculation module**, suitable machines are first selected for the rotational and non rotational parts from a database developed in the planning model. The required number of machines for demand forecast is then calculated and finally the monthly workloads are assigned to the calculated machines.

The KB system performs a careful analysis of the MHSs in the **MHS calculation module** by considering various design factors and using three known arrangements of the machine tools on the shop floor (viz. single row, double row and loop layouts). The KB system selects the best layout that offers the optimum values of the considered design factors.

In the **quality control module**, the KB system checks the dimensions of each part produced (performing 100% inspection). Simple statistical techniques for quality control are applied thus setting the upper and lower limits for each part type (each part type has it's own batch size). If any of the dimensions of a part is found out of limit, then the KB system arrives at a decision, i.e. either to accept the part for rework or reject.

Finally, the KB system checks the viability of the CIM system using a **financial assessment module**. A detailed cost analysis is performed in this module by using various techniques such as Break Even Analysis (BEA), Net Present Value (NPV), Internal Rate of Return (IRR) and Pay Back Period (PBP). If the CIM system is financially not feasible then the KB system provides suggestion and refers the user to review some of the inputs provided at the planning stage.

5. ILLUSTRATIVE EXAMPLE

The KBCIMS model is illustrated through an example. This model requires a large amount of input data, however, for demonstration purpose, only important figures are considered. 28 different part types (12 rotational and 16 non rotational) with a total demand of 26047 parts per year are considered. The monthly operation times on rational and non rotational parts are considered as 369 hours and 971 hours respectively. It is assumed that the CIM system operates 24 hours per day. Considering the operating days per month and mechanical and utilization efficiency of the system, the CIM system is available for 451 hours per month.

KBCIMS model incorporates both rules and analytical procedures. Some of the rules are given below to demonstrate the selection/decision process used at different modules. In the machine calculation model, the KB selects the machines as:

IF *machine 1 can accommodate maximum size of the part types*
AND *machine 2 can accommodate maximum size of the part types*
AND *there is no technological constraint*
AND *machine 1 costs less than machine 2*
THEN *select machine 1*
OR *check other set of rules*

Table 1 shows only the number of required machines. The load assignment to these machines is not shown here.

Table 1. Machines calculation

Availability of the CIM system per month (hours)	451
Monthly operating hours on rotational parts	369
Monthly operating hours on non rotational parts	971
Number of machine(s) for rotational parts	1
Number of machine(s) for non rotational parts	3
Total number of machines required	4

In the MHS selection module, the KB arrives at a decision as follows:

IF *parts moves through short to medium distances*
AND *parts travel path is variable for product mix*
AND *new routes can be easily added in case of machine breakdown*
AND *shop floor congestion should be avoided*
THEN *select AGV as an MHS*
OR *Trigger other set of rules*

Table 2 below shows, some of the design factors calculated for the selected MHS (AGV system in this example).

Table 2. MHS design factors

Design Factor	Single Row layout	Double Row Layout	Loop Layout
A_d	10.83	7.83	7.8
A_e	3.82	3.32	1.11
T_d	15.73	12.04	9.68
N_d	3.75	4.93	6.17
N_{agv}	4	4	3
η_{mhs}	72.65	69.54	87.18
R_n	2	2	2

The results shown above in Table 2 are the result of the combination of two assumptions. Both assumptions represent two extreme cases for the delivery and empty moves, whilst the combination represents more realistically the pick up and drop off situations.

Table 2 shows that the loop layout provides better results for the considered design factors such as average distance travel per delivery (A_d , 7.8 m), average distance travel per empty move (A_e , 1.11 m), total time per delivery (T_d , 9.68 min.), number of deliveries per hour per vehicle (N_d , 6.17), number of AGVs (N_{agv} , 3) and efficiency of the MHS (η_{mhs} , 87.18%). The number of robots to load and unload parts are calculated the same, i.e. (R_n , 2). A scoring model is used to calculate weights for all the design factors considered in the KBCIMS model. The KB system selects the best option.

In the LAN selection module, the KB system selects the LAN as follows:

IF *equipment meets openness standard*
AND *frequency of data in burst form*
AND *data size limited*
AND *transmission is deterministic for high level of traffic*
AND *functions are time critical*
THEN *bus network, MAP/EPA as protocols, token passing to access LAN, co-axial cable as transmission line and carrier band as bandwidth*
OR *Trigger other set of rules*

Similarly rules are used in other modules. Table 3 shows, some of the cost information and feasibility of the model.

Table 3. Cost information

Total Investment required for the considered information	20 millions SR
Loan	12 millions SR
Equity or outlay	8 millions SR
Break even	18.72%
Internal rate of return	33%
Payback period based on inflow per year	2.46
Payback period based on net present value	3.03

As the rate of return is quite healthy and also the total investment can be returned within very reasonable period of time, therefore, the information considered by the KBCIMS model is found feasible.

6. CONCLUSIONS

The KBCIMS methodology is developed in two stages using rules and analytical methods. The first stage (planning) acquires information about the demand forecast, process plan, machines, MHSs and LAN. Upon the successful information acquisition and detailed analysis in the planning stage, the next stage (design) is loaded. In the design stage, suitable machines are selected and calculated, suitable MHS is selected and design factors calculated, quality control techniques applied and finally an in-depth cost analysis is performed to check the viability of the designed CIM system. Although the KBCIMS is generic it can certainly assist the planners and designers in specific situations.

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REFERENCES

1. Aguiar, M.W., and Weston, R.H., 1995, "A Model-Driven Approach To Enterprise Integration", *International Journal of Computer Integrated Manufacturing*, 8, pp 210-224.
2. Al-Ahmari, A. M. A., 2002, "Implementing CIM systems in SMEs" *International Journal of Computer Applications in Technology,* 15, pp 122-127.
3. AM, 1995, Intelligent Environments, Middlesex, UK.
4. Beynon-Davies, P., 1993, Knowledge Engineering for Information Systems, McGraw-Hill Book Company.
5. Brandimarte, P. and Cantamessa, M., 1995, "Methodologies For Designing CIM Systems: A Critique", *Computers in Industry*, 25, pp 281-293.

6. Chadha, B., Jazbutis, G., Wang, C., and Fulton, R., 1991, "An Appraisal Of Modelling Tools And Methodologies For Integrated Manufacturing Information Systems: Engineering Databases", *An Engineering Resource ASME*, pp 55-63.
7. Doumeingts, G., Vallespir, B., and Chen, D., 1995, "Methodologies For Designing CIM Systems: A Survey", *Computers in Industry*, 25, pp 263-280.
8. Drenth, H., and Morris, A., 1992, "Prototyping Expert System Solutions: An Evaluation Of Crystal, Leonardo, GURU, And ART-IM", *Expert Systems*, 9 (1), pp 35-45.
9. Edwards, J. S., 1990, Building Knowledge Based Systems, Pitman.
10. Fossum, B., and Ettlie, J., 1990, "The reconciliation of MIS and manufacturing for integrated manufacturing", *NIST Publication 785, Proceedings, CIMCON* ,90, Gaithesburg, pp 306-325.
11. Guetari, R., and Nguyen, G.T., 1997, "The 3DOM Object Model For The Design Of Manufacturing Systems", *International Journal of Computer Integrated Manufacturing*, 10, pp 51-60.
12. Gunasekaran, A., 1997, "Implementation Of Computer Integrated Manufacturing: A Survey Of Integration And Adaptability Issues", *International Journal of Computer Integrated Manufacturing*, 10, pp 266-280.
13. Hassard, J., and Forrester, P., 1997, "Strategic And Organisational Adaptation In CIM Systems Development", *International Journal of Computer Integrated Manufacturing*, 10, pp 181-189.
14. Jackson, P., 1990, Introduction to Expert Systems, Addison-Wesley Publishing Company.
15. Kusiak, A., 1991, Intelligent Manufacturing Systems, Prentice Hall.
16. Mital, A., and Anand, S., 1994, Handbook of Expert Systems Applications in Manufacturing-Structures and Rules, Chapman and Hall.
17. Nicholson, H., 1991, Integrated Manufacturing Systems - The Problems of Advanced Manufacturing, Short Run Press Ltd.
18. Owen, T., 1987, Expert Systems: The Key Facts for Decision Makers, Cranfield Press.
19. Pandya, K.V., 1995, "Review of modelling techniques and tools for decision making in manufacturing management", *IEEE Proceedings on Science, Measurement and Technology*, 142, pp 371-377.
20. Pleinevaux, P., 1997, "CCE: The CIME Computing Environment", *International Journal of Computer Integrated Manufacturing*, 10, pp 117-125.
21. Sarkis, J., and Lin, J., 1994, "An IDEF0 Functional Planning Model For The Implementation Of CIM Systems", *International Journal of Computer Integrated Manufacturing*, 7, pp 100-115.
22. Savolainen, T., Beeckmann, D., Groumpos, P., and Jagdev, H., 1995, "Positioning Modelling Approaches, Methods And Tools", *Computers in Industry*, 25, pp 255-262.
23. Singleton, D., 1991, "Expert Systems: Overview Of Features They Provide", *Computer, Environment, and Urban Systems*, 15, pp 287-301.
24. Tsai, J. J. P., Yang, S. J. H., Waheed, N., and Moher, T., 1993, "Development Of Expert System Shells, In: Knowledge Engineering Shells-Systems And Techniques", N. Bourbakis (Ed.), *World Scientific*, pp 123-152.
25. Turban, E., 1995, Decision Support and Expert Systems, Prentice-Hall International Inc.
26. Vail, P.S., 1988, Computer integrated manufacturing, PWS-Kent Publishing Company.

Top