

Graph Theoretic Modeling and Analysis of Computer Integrated Manufacturing System

Thesis Report
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in

**Production & Industrial
Engineering**

by

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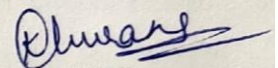
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Declaration

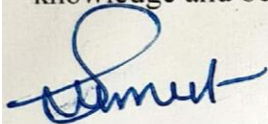
I hereby declare that the minor project report entitled “**Graph Theoretic Modeling and Analysis of Computer Integrated Manufacturing System**” is an authentic record of my study carried out as requirements for the award of the degree of Master of Engineering in Production & Industrial Engineering at Thapar University, Patiala under the supervision of **Mr. Sumeet Sharma**, Associate Professor, Mechanical Engineering Department, Thapar University, Patiala and **Dr. S. K. Mohapatra**, Sr. Professor & Head, Mechanical Engineering Department, Thapar University, Patiala.

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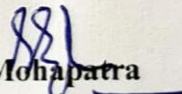
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It is certified that the above statement made by the student is correct to the best of our knowledge and belief.



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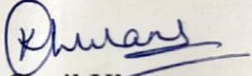
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Govil Khurana

Abstract

CIMS is very important manufacturing process and there are various factors affecting the outcome of the process. In this work modeling and analysis of the CIMS is done using graph theoretical approach. The graph theoretical approach is an analytical approach. Firstly different subsystems of the system are identified. Then these subsystem and their interactions are displayed in a structural graph made from a digraph. These subsystems and interaction are represented in a matrix form to make it easy for analysis. From this a permanent matrix and a permanent function are developed. The permanent function comprises of all the characteristics features of the system. Numerical values can be assigned to the subsystem and their interaction depending on their influence on the system. These values can be used to obtain a permanent index of the system from the permanent function. This index is used for comparing different systems in which any of the parameters can be changed to obtain new index value. The main benefit of this methodology is that it can be deployed at the conceptual stage and optimum system parameters can be selected for the particular process.

Abbreviations

CIM	Computer Integrated Manufacturing
CAD	Computer-Aided Design
CAM	Computer Aided Manufacturing
FMS	Flexible Manufacturing Systems
CNC	Computer Numerically Controlled
RP	Rapid Prototyping
CAPP	Computer-Aided Process Planning
CAE	Computer-Aided Engineering
CIMSPM	Computer Integrated Manufacturing System Characteristic And Interdependence Variable Permanent Matrix

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CHAPTER 1

INTRODUCTION

1.1 CIMS (Computer Integrated Manufacturing System)

CIM has a basic concept, to format a mutual database to clench the majority part of information essential to ride a manufacturing company. CIM concept has drastically progressed now. The expansions of the factories future prospective, architectures all should now accumulate the introduction of this new technology for the production flexibility and also for the changes in social attributes in an organisation. [13]

CIM denotes to computer-oriented technology used to design, logistics and manufacturing. This technology is characteristically includes following major parts: computer aided manufacturing (CAM), computer-aided design (CAD), industrial robotics, group technology, automated material handling systems, flexible manufacturing systems (FMS), rapid prototyping (RP) processes, and computer numerically controlled (CNC) machines.[34]

1.2 Challenges to be faced

There are total three numbers of hurdles for development of an efficiently operating of CIM system:

- a) The suppliers components need to be integrated.
- b) Data Integration: To govern the machines, integration of automation must be with higher degree.
- c) Control on Process Parameters: Computers are helping hand to assist the human operators for the manufacturing facility, but there is always a requirement of a competent engineer on hand to take care the circumstances which cannot be condoned by the designers of the control software.

1.3 Field of Application

Below mentioned are the areas, where it can be used:

- ❖ In the Production Engineering companies.
- ❖ In the Mechanical Engineering.
- ❖ For the design of electronic automation such as PCB (Printed Circuit Board) and integration of circuit design data for manufacturing.

1.4 CAD (Computer-aided design)

The basic tool to create, modify, analyse, or optimize a design with the help of a computer is CAD. CAD software which enhance the efficiency of the designer, exaggerate design quality, communicate with documents and to generate a database for production of a part. The output of the CAD is often in an electronic file and then can be printed, with the print part can be machined or manufactured.

1.5 CAE (Computer-aided Engineering)

Computer-aided engineering is basically use of different software's for the analysis of the manufactured parts. The areas of software's are FEA (Finite elements Analysis), Computational Fluid Dynamics and MBD.

1.6 CAM (Computer aided Manufacturing)

Computer-aided manufacturing (CAM) is basically usage of computer software's to manufacture parts by governing the machine tools and associated machine. We can define the CAM in many different, but it best communal; we can also define CAM as use of computers to assist in all operations of a manufacturing plant, planning of the manufacturing, tools management, transport of produced parts and inventory.

1.7 CAPP (Computer-aided process planning)

Computer-aided process planning is used for planning of a process with the help and guidance of computer for the manufacturing of a part. CAPP is the bridge between CAD and CAM that delivers the planning process that can be followed for production of a designed part.

1.8 CAQ (Computer-aided quality assurance)

Computer-aided quality assurance (CAQ) is the tool, in which computers are used for characterizing and inspecting the quality of the products.

1.9 Benefits

- ❖ In real time we can detect the problems on the machines or flowchart of work and if found required amendments can be implemented faster.
- ❖ Cost savings is also big part which can be achieved.

- ❖ Better application of equipment which results in to purchase less parts and decrease the labour.[35]

1.10 Drawbacks

- ❖ Investment can vary from a single equipment to complete factory setup.
- ❖ Design, manufacturing and administration require sufficient investment.
- ❖ Technologies like machining centres, automated storage and retrieval system etc. call for plenty of funds.[35]

1.11 Graph theory

Graph theory is defined in many different ways by mathematicians and in computer language. It is simply the study of graphs, in which different objects are modelled in pairs structured in mathematical model.

1.12 Applications

Graph theory can be applied widely in abundant disciplines to structurally model the system and analyse them in a structured way.

Three different steps of applying Graph-theory:

- Digraph Method of representation: A digraph is the representation of the structured the system using edges and nodes. The characteristics (a_i, i) represents the how to measure the nodes and edges represents the requirement of characteristics (a_{ij}, e) . a_{ij} means the degree of quality required of the f^{th} on to the g^{th} character.[25]
- Matrix Method: As everything has limitations, digraph representation just represents a visual presentation and helps the analyst to analyse the problem but upto limited extent only. With perspective to this, In matrix method, the graph is made with one-to-one representation and digraph is made. The result of matrix will be $M \times M$ when there are M nodes in the digraph, diagonal elements represents the characteristics (a_i, i) and non diagonal represents the dependence of the characteristics (a_{ij}, e) . Matrix obtained is also known as variable permanent quality matrix. [25]
- Permanent function representation: the mathematical expressions achieved without any loss of data or informations of the measures, the variable permanent quality matrix is used. This expression acts as a representative of the system and consists of all possible terms of the system.[25]

1.13 Advantage

The crystal clear advantage of the graph theoretical approach is that maximum number of parameters which can affect the system can be measured in totality, and the permanent variable index can be established in the work and would then signify the whole consequence in a systematic manner [56].

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

CIMS is very important manufacturing process. Many factors affect the outcome of the product through the process. So studying its behaviour is important. Researchers have been studying the process for a long period of time. Applying to graph theory to this process will help predicting the outcome at an early stage. Some of the literature on the CIMS and graph theory are mentioned below.

2.2 Literature Review

Gandhi et al. (1991) [3] presented how graph theoretical approach can be used to model the reliability of a mechanical and hydraulic system. The optimum selection of system could be done at the initial stage using the proposed matrix permanent index.

H.-P. Wiendahl et al. (1991) [2] detailed that the development of CIM systems has encouraged and build up a different subsystem in an evolutionary way. In present days the CIMA has been executed in large scale industries for the smooth mass production but in small scale industries its still not in existence or preferred. Due to lack of awareness in industries or organisations that CIM can integrate the productivity to higher rate Small scale industries hard to implement it. There CIM centres existing these days which guide and find the solutions of the problems occurring during manufacturing add onto this these centres guide too. Taking into consideration different prospective after finding the problems in manufacturing the CIM will define it into matrices. For future, importance of the standardization of organizational interfaces with which we can characterize decision integration will increase. Another step for the complete integration of companies seems to be the considered and integration of administrative areas, where we can characterize by the term Computer-Integrated Office (CIO) and add on to that the concern of the logistical aspects. The summation of CIM and CIO will be the realization of the whole logistical chain which will be the challenge of future.

Gandhi and Agrawal (1992) [4] projected the method of failure mode and effect analyses (FMEA) of mechanical and hydraulic systems by graph theoretical method. The everlasting

function of interrelated elements of FMEA of the system was developed and can be used for identification of various components of failure coming during the production and effects on the manufacturing. This system can also be used for comparing other FMEA systems.

Gandhi and Agrawal (1994) [8] diagnosed an analysis procedure for the analysing wear characteristics of mechanical components using graph theoretical approach. Several wear factors and there degrees of influence among each other, which conclude wear independence and wear process between the components, were recognised. The permanent function of the system developed was used for quantification and comparison of different subsystems. This can also be a helping hand for optimum selection of subsystems on the basis of wear characteristics.

Gandhi and Agrawal (1996) [17] had evaluated the graph theoretical based approach for failure cause analyses. The development of failure causality digraph models, failure contributes to events and their communications in terms of cause-effect relationship. This technique can also be helping hand for identification, comparison and evaluation of failure causes.

M. Anwarul Islam et al. (1997) [20] quantified that selection of database for computer integrated manufacturing (CIM) system acts as a important issue in system design. With the help of this evidence, no single database model was able to satisfy all the requirements of a system. Many types of manufacturing requirements require different database models depending on the desired application. Here Analytic Hierarchy Process (AHP) is used for the selection of an appropriate database model for a CIM system. Where as many contradictions with Analytic hierarchy process technique gives an image of being the most efficient tool to define the database of a Computer Integrated Manufacturing system

Venkatasamy and Agrawal (1997) [25] obtained graph with theoretical approach for quality evaluation system automobile vehicles. Total 12 quality characteristics like performance, reliability, durability, conformance, serviceability etc. were recognized. The permanent function developed from the permanent matrix containing all the subsystems and their interactions can be used for evaluation and comparison of various alternative vehicles.

Jason Z. Yin (2002) [32] had surveyed that with rapid advancement in mechanical as well electronic technology, computer-integrated manufacturing (CIM) systems has incremented to help, the users to increase productivity, work with more flexibility, speed and quality.

Therefore, an organisation has to learn the application of the CIM system for the broad help. This learning helps in making the relation between organizational learning and also helps in increasing the capability to perform the problem definitions. Total 124 firms data, predicted that CIM techniques are helping hand for learning techniques to resolve the problems in companies.

Mustafa Yurdakul (2004) [35] stated that the investigating the number of problems using in computer-integrated manufacturing (CIM), which is a sum of qualitative as well as quantitative factors. For the selection of the best solution either qualitative or quantitative, one has to get eliminated, to get rid off the conflicts. Selection plays a vital role in manufacturing plants for long lasting companions adds on to this it require a model selection. The selected model consists of both the quantitative as well as qualitative constraints. The combination of these model is a proposal to consider the multiple constraints and objectives.

Sandeep Grover et al. (2004) [37] had identified various factors which are responsible for the TQM environment. The factors which were identified were directly or indirectly connected to each other by different factors. This attempt was made for developing a simple model of mathematics of the TQM. This attempt was made with the help of graph theoretical approach. The digraph obtained represented abstracted information with the help of the directed edges that came out with result of visual analysis. This model was helpful for the processing of computers. A fixed value was derived and this method resulted to be very flexible to accumulate new matters related to market for global business and continuous innovation and development.

Mohan et al. (2004) [38] made a preservation strategy using a graph theoretical approach for the coal-based steam power plant equipment. All the equipment of the plant were classified into numerous principles and sub-criteria having relations like maintenance effort, loss of production, safety, dependability etc. The matrix established using these criteria were used for planning, analysing and relating alternative maintenance strategies.

Grover et al. (2005) [39] developed mathematical model for calculating the performance of human resources in TQM using graph theoretical approach. The matrix developed comprises of all the factors representing the involvement of the human in an organisation. This can be used to expand various TQM cultures across the industries and compare them too. Also

SWOT (Strengths, Weaknesses, Opportunities, and Threats) study can be done by applying this method.

Kumar and Agrawal (2008) [44] proposed a method using the graph theoretical to model and analyse an electroplating system of a company. The developed method identifies the sub system and the interaction, generated the alternative solution to design. Optimal solution achieved can be used for the precise selection of the design. The method can be helpful to perform alterations in design, conceptually used for the optimum solution which results into permanent function.

Abhishek Kumar et al. (2010) [46] had made an effort to address some minute ecological and environment issues with the help of different types of structural models used for the treatment system of an electroplating. This treatment system was helpful for minimizing the waste in the industry by using the different subsystems related to it. Hierarchical tree and block diagram were proposed by interacting with different subsystem which was proposed. All the non mathematical diagrams were converted into mathematical matrices to enhance, examine etc of the design. The results were achieved using graph theoretical model, matrix model and permanent function model. Permanent function, hierarchical tree and block diagram methods was used for the analysis and for the storage and retrieval matrix models was used.

Jangra et al. (2010) [49] established a performance evaluation method based on graph theoretical approach for carbide compacting die developed by wire EDM. Several factors disturbing, die performance and comparisons were analysed with the help of mathematical model. For comparing and ranking the factors affecting the die performance, permanent function was developed from the matrix model. This is beneficial in selection of best process parameters for the manufacturing of a die. In this study numerous factors which affects the performance of the electroplating were removed and found that machine tool was the major factor affecting the performance.

Rajesh Attri et al. (2014) [54] published about Total productive Maintenance (TPM) is an pioneering approach to maintenance that helps the potential for better upliftment of effectiveness of production facilities but the reason of implementation of TPM is difficult task. Immeasurable barriers are always in between in real-life cases during TPM application. It is very important to calculate the nature and impression of all the incoming barriers reason

behind that production and maintenance managers will be able to develop some strategies to cross these barriers. For present exertion the graph theoretic approach has been applied to calculate the maximum intensity of the barriers via an index which is calculated with the help of a permanent function derived from the digraph of TPM barriers.

Dwarikanath Ratha et al. (2015) [55] developed the basic quantitative model based on which the graph theory is used for the improvement in management and development of watershed, factors affecting the system were identified and their interaction was determined. The matrix model for the system comprising various subsystems and their interactions was developed. The multinomial developed from the matrix can be used to find the optimum solution by comparing the index value with the different alternatives.

2.3 Gaps in literature

Based on the above review, the following gaps have been identified in the available literature:

1. The implementation of computer integrated manufacturing needs the analysis of decisions at the conceptual stage which is not supported by the studies in the literature.
2. A structure based model is required for analysis of computer integrated manufacturing system which is always helping hand for the incorporation communications and interdependences between different subsystems.
3. There is significant scope for exploring the use of graph theoretic methodology, which has been useful in modeling different other complex systems.

CHAPTER 3

GRAPH THEORITIC APPROACH

3.1 Major Points of Assumption

Main Points to taken into consideration for the desired graph theoretic model of CIMS (computer integrated manufacturing systems) are given below:

- a) Performance can be quantitatively associated with the structure of the system.
- b) The subsystem and their interactions are for a general CIM system and cannot be applied to a specific model.
- c) Organization's aim and objective play a vital role in selection of subsystem and their interactions for the system.
- d) The CIM system is completely represented by the variable permanent matrix as its diagonal and non-diagonal elements represent the subsystems and their interactions respectively.
- e) From the structural point of view the CIM system is uniquely characterized by the permanent function.
- f) The single performance of subsystems with the attached components along with the relations/interdependence/effects between them, considered to be main performance indicators of a computer integrated manufacturing system.
- g) Modeling of the problem is done by following the bottom up approach. Permanent functions of the matrix of a sub system are helpful and used to perform calculations of the whole CIMS.
- h) The numerical score obtained by assigning appropriate values to various elements by experts can be started at the bottom level.

3.2 Identifications of the subsystem of CIMS

The five subsystems are used for description of the methodology which is database, design, planning, manufacturing and quality subsystems. These subsystems are the general assumption in CIMS and all the important criteria, creates an mirror image the assumed subsystems. These subsystems may change depending on the requirements of the CIMS(computer integrated manufacturing systems). Therefore the desired models will be in

capability, for any kind of variations and it will be fit for designing or modeling any structure of the CIMS.

3.3 CIMS (Computer Integrated Manufacturing System)

The tree diagram shown in fig 3.3.1 contains all the accumulated data related to the above identified five subsystems.

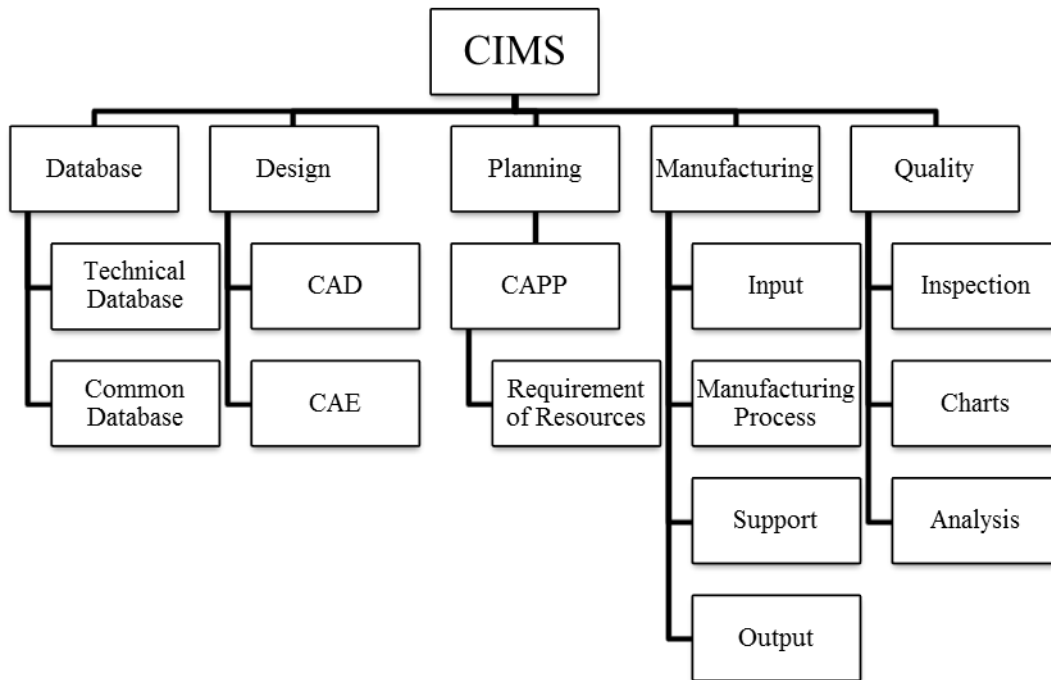


Figure 3.3.1: Represents the CIMS tree diagram

Database subsystem

Database is the collection of all the past and present data related to any product manufactured by company. It contains list of raw materials, the designs of various products, the planning required for the manufacturing, the processes followed during the conversion of raw material to finished goods, the quality of the product obtained, the cost of operating and manufacturing etc.

Design subsystem

Design of any product is very important aspect of the manufacturing process. It helps us in determining the minimum size of the raw material required to make an effective product and what processes are to be followed during the same.

Planning subsystem

Planning plays a vital role in the manufacturing process. It details the step by step path to be followed during the manufacturing for minimum cost. Proper planning of the product to be made can drastically reduce the ideal time and increase the profit.

Manufacturing subsystem

Manufacturing is the conversion of raw material into finished goods. It contains all the machining processes required during the process and is a major part of the computer integrated manufacturing system.

Quality subsystem

Quality determines whether the final product obtained is of the predefined specifications as required by the customer. This also determines whether the machines used during the process are properly working as required or need some maintenance.

3.4 Connections in the subsystems of the computer integrated manufacturing system (CIMS)

Fig 3.4.1 represents the interactions between the various subsystems which were not shown in fig 3.3.1 regardless of showing all the subsystems. Some of the features are discussed below.

The database has direct influence over the design subsystem as the pervious available designs decreases the time to complete the work and hand over the designs to the planning department. Also any design for new product can be stored in the database for any future reference.

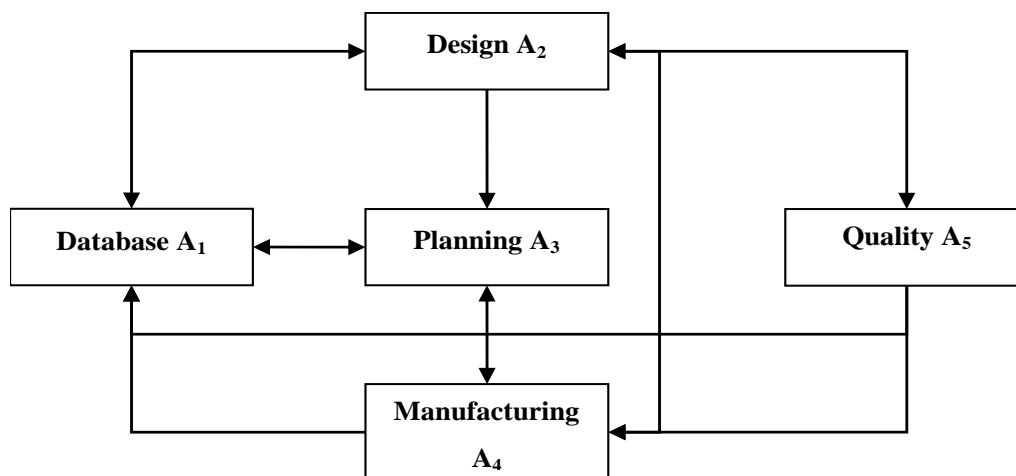


Figure 3.4.1: Represents computer integrated manufacturing system(CIMS)

The planning subsystem is directly influenced by the database subsystem as any available planning related to the product manufacturing reduces the time at this stage and increases profit. Also planning done for any new products can be stored in the database to be used in the future.

Planning subsystem is influenced by the design subsystem as it requires design for the product to be manufactured a lay out a detailed step by step path to be followed during the manufacturing.

Design and manufacturing subsystems are interrelated as it provides the specifications of the product and any difficulty faced during the manufacturing is conveyed to the design subsystem for appropriate changes.

Quality subsystem is directly influenced by the design subsystem as only the product design can tell the quality department the specification in which the product has to be approved. Also the specification of the product obtained has to be conveyed to the design team to analyse the results.

Manufacturing subsystem is directly influenced by the planning subsystem. The step by step path laid by the planning department helps in reducing the ideal time during the manufacturing process and increases the profitability of an organization. Similarly manufacturing department has to convey to the planning department of any problems in following the steps or machine failure to update the path for least possible downtime.

Database is directly influenced by both the manufacturing and quality subsystem as it stores all data related to the product for future reference.

Quality subsystem influences manufacturing subsystem by providing the data related to quality of the product to make any change required in the process.

3.5 Graph theoretic approach of the computer integrated manufacturing system

Figure 3.4.1 is a précised representation of interconnection between the subsystems of the computer integrated manufacturing system (CIMS). There are many enormous applications models graph theory and these models were defined with background of mathematics (Deo,2000). Out of these applications some of them, consists the model for the power plant problems and solutions (Mohan et al, 2003), composites materials (Dural Prabhakaran et al.,

2006), etc. Xu et al (2002). All of them used graph theory due collaborate and express the data into a collage. Hence, it is quite obvious and reasonable to consider the graph theory and matrix algebra (Jurkat and Ryser, 1966), because of the modeling of the computer integrated manufacturing system,

Due to this reason, a linear graph, H has been used as a function of vertex and edge set as $H = L(A,M)$, where A corresponds to a set of vertices $A = \{A_1; A_2; . . . ; A_n\}$ and M corresponds to a set of edges $M = \{m_{12}; m_{23}, .. m_{mn}\}$ joining different vertices.(Deo, 2000).

In the instance of the CIMS, vertices represent the subsystems (A_i) and the edges (m_{ij}) represent the interconnection and connectivity from subsystem A_j to subsystem A_i . The graph of CIMS is an addressed graph for edge direction defines a specific to the interactions. Therefore, edge linking of same two subsystems and addressing in an opposite directions shows a different interaction ($m_{ij} \neq m_{ji}$). The obtained graph of CIMS has been shown as in figure 3.5.1.

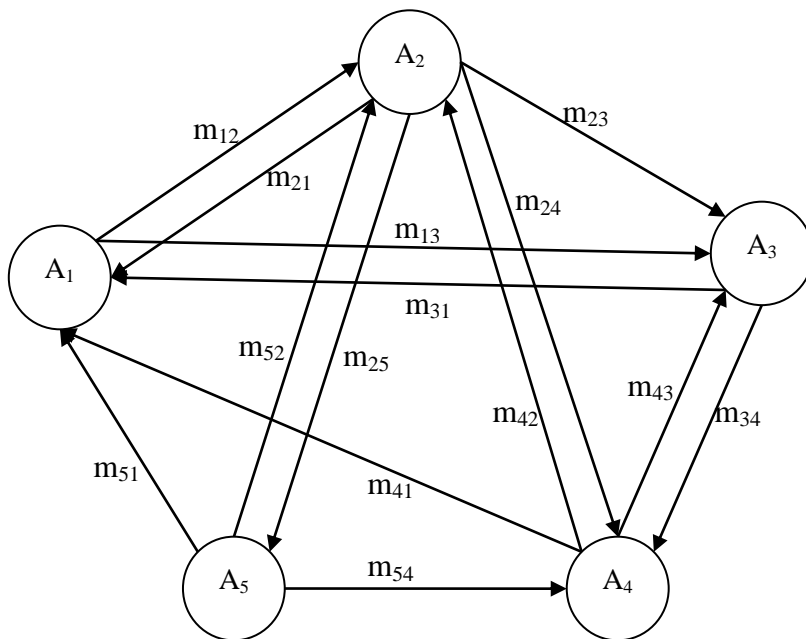


Figure 3.5.1: Presents the structural graph of CIMS

The above manufacturing system graph is a practical mathematical body and is very helpful in understanding as well as the presentation of the manufacturing system. But, it has a drawback i.e the derived information cannot be stored in the computers for the analysis. For attainment of this goal, CIMS can be represented in the form numerous matrices and connected models as designated in the next section.

3.6 CIMS Matrix Representation

Many methods have been researched or developed for the representation of graph in the matrix but according to literature review the two methods are very useful. i.e Incidence and Adjacency method (Deo,2000). The adjacency matrix is preferred due to reason of the square matrix and it helps for getting an algebraic results.

Adjacency matrix

The adjacency matrix of the graph G will be a fifth order binary (0, 1) square matrix consists five nodes, $S = [s_{ij}]$ like:

$$s_{ij} = \left. \begin{cases} 1, & \text{if subsystem } i \text{ have an influence on subsystem } j \\ 0, & \text{if } i \text{ and } j \text{ are not connected} \end{cases} \right\}$$

where $i, j \in \{1, 2, 3, 4, 5\}$ and $i \neq j$.

Thus, the adjacency matrix, S for the computer integrated manufacturing system graph, G is inscribed as below:

$$S = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \begin{matrix} \text{subsystems} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \end{matrix} \begin{bmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \end{bmatrix} \quad (3.1)$$

Characteristics of Matrix

The above matrix A only represents the interactions and not the characteristics of the system. To overcome this problem, matrix B was developed in equation 3.2 and named CIMS characteristic matrix.

$$B = [\lambda I - S] = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \begin{matrix} \text{subsystems} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \end{matrix} \begin{bmatrix} \lambda & -1 & -1 & 0 & 0 \\ -1 & \lambda & -1 & -1 & -1 \\ -1 & 0 & \lambda & -1 & 0 \\ -1 & -1 & -1 & \lambda & 0 \\ -1 & -1 & 0 & -1 & \lambda \end{bmatrix} \quad (3.2)$$

Whereas we have represents λ as eigen values for the matrix; I as the identity matrix of same order as S.

The determinant obtained in equation 3.3 from the matrix in equation 3.2 is invariant as the subsystems and their interactions are not uniquely represented.

$$\text{Det}(B) = \lambda^5 - 5\lambda^3 - 6\lambda^2 - 2\lambda - 1 \quad (3.3)$$

The characterization of the system cannot be done on the above determinant completely as it is not able to discriminate between various subsystems and their interactions.

Computer integrated manufacturing system characteristic and interdependence variable matrix

The CIM subsystem characteristic and interdependence variable matrix (CIMSSCIVM), C, is developed in equation 3.4 to present various subsystems and their interaction which was not available in matrix B.

To resolve the above problem, the matrix C developed is a sum of two square matrices of fifth order namely D and E containing diagonal elements A_i , subsystems and off-diagonal elements m_{ij} , subsystem interactions respectively.

$$C = [D-E] = \begin{array}{ccccc} & \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \begin{matrix} \text{subsystems} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \\ \begin{matrix} A_1 \\ -m_{21} \\ -m_{31} \\ -m_{41} \\ -m_{51} \end{matrix} & \begin{bmatrix} -m_{12} & A_2 & 0 & 0 \\ 0 & -m_{23} & A_3 & 0 \\ -m_{42} & -m_{43} & A_4 & 0 \\ -m_{52} & 0 & -m_{54} & A_5 \end{bmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix} \end{array} \quad (3.4)$$

This matrix particularly characterizes their interactions and characteristic features of the subsystems. Therefore, the matrix C in equation (3.4) is whole structural illustration of the computer integrated manufacturing system showing all the data associated with manufacturing system plus their interactions. But it does not characterize the CIMS distinctively as already discussed in the previous subsection.

As already discussed in the previous subsection, the determinant of matrix C is an invariant of the manufacturing system and is established as shown in equation (3.5) below. It has been named as CIMS characteristic and interdependence variable multinomial.

$$\begin{aligned} \text{Det}(C) = & A_1A_2A_3A_4A_5 - A_1A_2A_5m_{34}m_{43} - A_1A_5m_{23}m_{34}m_{42} - A_1A_3A_5m_{24}m_{42} - A_3A_4A_5m_{12}m_{21} \\ & + A_5m_{12}m_{21}m_{34}m_{43} - A_4A_5m_{12}m_{23}m_{31} + A_5m_{12}m_{23}m_{34}m_{41} - A_5m_{12}m_{24}m_{43}m_{31} \\ & - A_3A_5m_{12}m_{24}m_{41} - A_5m_{13}m_{34}m_{42}m_{21} - A_2A_4A_5m_{13}m_{31} - A_2A_5m_{13}m_{34}m_{41} \\ & + A_5m_{13}m_{31}m_{24}m_{42} - A_1A_3m_{25}m_{54}m_{42} - A_1A_3A_4m_{25}m_{52} + A_1m_{25}m_{52}m_{34}m_{43} \\ & - m_{12}m_{25}m_{54}m_{43}m_{31} - A_3m_{25}m_{54}m_{41}m_{12} - A_3A_4m_{25}m_{51}m_{12} + m_{25}m_{51}m_{12}m_{43}m_{34} \end{aligned}$$

$$+ m_{25}m_{54}m_{42}m_{13}m_{31} + A_4m_{25}m_{52}m_{13}m_{31} + m_{25}m_{52}m_{13}m_{34}m_{41} - m_{25}m_{51}m_{13}m_{34}m_{42} \quad (3.5)$$

From the above equation, we can observe that the multinomial equation 3.5 can again be arranged in decreasing order of the $A_i \cdot m_i$ and then the equation can be classified into other six groups as given in equation 3.6(a).

$$\begin{aligned} \text{Det}(C) = & [A_1A_2A_3A_4A_5] + [-A_1A_2A_5m_{34}m_{43} - A_1A_3A_4m_{25}m_{52} - A_1A_3A_5m_{24}m_{42} - \\ & A_2A_4A_5m_{13}m_{31} - A_3A_4A_5m_{12}m_{21}] + [- A_1A_3m_{25}m_{54}m_{42} -A_1A_5m_{23}m_{34}m_{42} - \\ & A_2A_5m_{13}m_{34}m_{41} - A_3A_4m_{25}m_{51}m_{12} - A_3A_5m_{12}m_{24}m_{41} - A_4A_5m_{12}m_{23}m_{31}] + \\ & [\{A_1m_{25}m_{52}m_{34}m_{43} + A_4m_{25}m_{52}m_{13}m_{31} + A_5m_{12}m_{21}m_{34}m_{43} + A_5m_{13}m_{31}m_{24}m_{42}\} + \\ & \{-A_3m_{25}m_{54}m_{41}m_{12} + A_5m_{12}m_{23}m_{34}m_{41} - A_5m_{12}m_{24}m_{43}m_{31} - A_5m_{13}m_{34}m_{42}m_{21}\}] + \\ & [\{m_{25}m_{52}m_{13}m_{34}m_{41} + m_{43}m_{34}m_{25}m_{51}m_{12} + m_{13}m_{31}m_{25}m_{54}m_{42}\} + \\ & \{- m_{12}m_{25}m_{54}m_{43}m_{31} - m_{25}m_{51}m_{13}m_{34}m_{42}\}] \end{aligned} \quad (3.6a)$$

The dyad (subsystems interactions loop) created from the above equations are L_{ij} , L_{ijk} , L_{ijkl} are actually loops of $m_{ij}m_{ji}$, $m_{ij}m_{jk}m_{ki}$ and $m_{ij}m_{jk}m_{kl}m_{li}$ respectively. Equation (3.6a) has been rewritten:

$$\begin{aligned} \text{Det}(C) = & [A_1A_2A_3A_4A_5] + [-A_1A_2A_5L_{34} - A_1A_3A_4L_{25} - A_1A_3A_5L_{24} - A_2A_4A_5L_{13} - \\ & A_3A_4A_5L_{12}] + [-A_1A_3L_{254} -A_1A_5L_{234} - A_2A_5L_{134} - A_3A_4L_{125} - A_3A_5L_{124} - \\ & A_4A_5L_{123}] + [\{A_1L_{25}L_{34} + A_4L_{25}L_{13} + A_5L_{12}L_{34} + A_5L_{13}L_{24}\} + \{-A_3L_{1254} + \\ & A_5L_{1234} - A_5L_{1243} - A_5L_{1342}\}] + [\{L_{25}L_{134} + L_{34}L_{125} + L_{13}L_{254}\} + \{-L_{12543} - \\ & L_{13425}\}] \end{aligned} \quad (3.6b)$$

3.7 Composite Performance index (CPI) and the permanent function

To obtain CPI (Composite performance Index) of the CIMs in a dimensioned way, the performance dimension can serve as an important factor to find the total performance analysis. The best way, use the appropriate numerical values of the CIMs in the above equations i.e. equation 3.6a and 3.6b. But using this method can some time lead to deletion of some data due to subtraction of some operations. To empower such limitations, permanent matrix and the permanent function can be used.(Jurkat and Ryser, 1966; Mine, 1966).

CIMs permanent matrix

Permanent matrix was derived when all negative sign of the elements in equation 3.4 were converted into positive. So, the derived matrix is named as CIMSPM i.e Computer Integrated manufacturing system permanent matrix. As shown below:

$$\begin{array}{cccccc}
 & 1 & 2 & 3 & 4 & 5 & \text{subsystems} \\
 P = & \left[\begin{array}{ccccc}
 A_1 & m_{12} & m_{13} & 0 & 0 \\
 m_{21} & A_2 & m_{23} & m_{24} & m_{25} \\
 m_{31} & 0 & A_3 & m_{34} & 0 \\
 m_{41} & m_{42} & m_{43} & A_4 & 0 \\
 m_{51} & m_{52} & 0 & m_{54} & A_5
 \end{array} \right] & \begin{array}{c}
 1 \\
 2 \\
 3 \\
 4 \\
 5
 \end{array} & (3.7)
 \end{array}$$

Computer integrated manufacturing system (CIMS) characteristic and interdependence variable permanent function

In equation 3.7 matrix P is a permanent function was developed with help of equation 3.8. differ from multinomial, Per P, permanent function and Det C in equation 3.6b. Both the number and type of terms evaluated were exactly same. Method of deriving the Det C and per P from the matrices is totally identical with exception no negative signs during the calculation time. Therefore, derived model has unique and complete solution of structures with the representation of CIMS and benefit was not losing data.

$$\begin{aligned}
 \text{Per}(P) = & [A_1A_2A_3A_4A_5] + [A_1A_2A_5L_{34} + A_1A_3A_4L_{25} + A_1A_3A_5L_{24} + A_2A_4A_5L_{13} + \\
 & A_3A_4A_5L_{12}] + [A_1A_3L_{254} + A_1A_5L_{234} + A_2A_5L_{134} + A_3A_4L_{125} + A_3A_5L_{124} + A_4A_5L_{123}] + \\
 & \{ [A_1L_{25}L_{34} + A_4L_{25}L_{13} + A_5L_{12}L_{34} + A_5L_{13}L_{24}] + \{ A_3L_{1254} + A_5L_{1234} + A_5L_{1243} + A_5L_{1342} \} \} + \\
 & \{ [L_{25}L_{134} + L_{34}L_{125} + L_{13}L_{254}] + \{ L_{12543} + L_{13425} \} \}
 \end{aligned} \quad (3.8)$$

In equation 3.8 numerical index achieved of permanent multinomial obtaining the numerical value into structural elements. These structural elements can be considered as a composite score of the whole manufacturing system in a defined dimension depending on the given value to individual element. This achieved score is a tool for the ranking as well as the comparison of CIMS design and optimal selections.

3.8 Assigning the derived values to variables

Based on the required performance level the numerical values of several subsystems and their interactions can be assigned by the experts working in the field.

If the system is complex, then the values can be chosen by decomposing the subsystems further into sub-subsystems. Thus, the numerical values for each subsystem variables A_1 , A_2 , A_3 , A_4 and A_5 may be obtained as below:

$$A_1 = \text{Per}(P_{A1}); A_2 = \text{Per}(P_{A2}); A_3 = \text{Per}(A_3); A_4 = \text{Per}(P_{A4}); A_5 = \text{Per}(P_{A5}),$$

where P_{A1} , P_{A2} , P_{A3} , P_{A4} , P_{A5} are the matrices for permanent variables of five subsystems.

The single index value obtained for the evaluation of the system can be obtained by analysing every level starting at the bottom giving complete assessment of the system.

3.9 CIMS structural analysis

Numerous expressions of the permanent multinomial in equation (3.8) consist of the structural elements such as subsystem features (A_i 's) and connections (m_{ij} 's). The elements such as $m_{ij}m_{ji}$, $m_{ij}m_{jk}m_{ki}$, $m_{ij}m_{jk}m_{ki}$ in a multinomial term make a relationship with the subsystems interrelating in the form of a dyad, three, four or five subsystems in a loop. These terms correspond to the real subsets of the CIMS structure. These all terms are grouped together with each of the group for the multinomial to form a different set, which may be used for characterizing/differentiating the CIMS exclusively.

These unique subsets of the total manufacturing system identified from equation (3.8) below may be characterised as subgroups as in Figure 3.9.1.

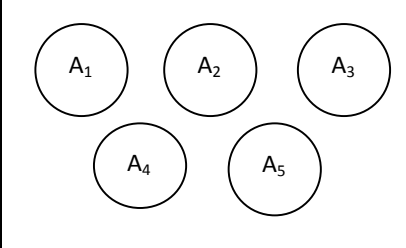
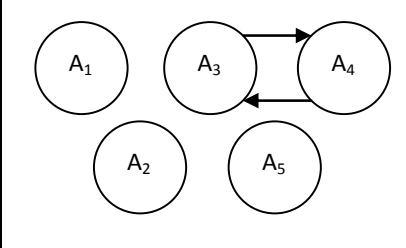
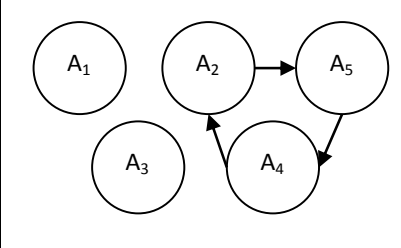
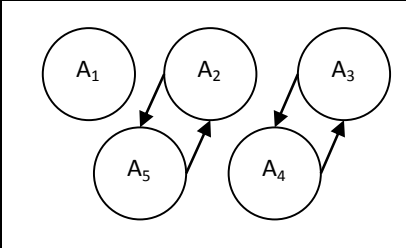
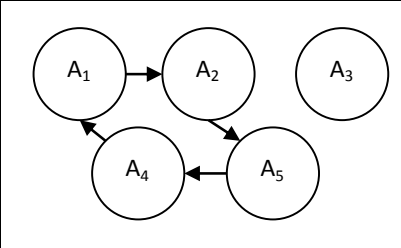
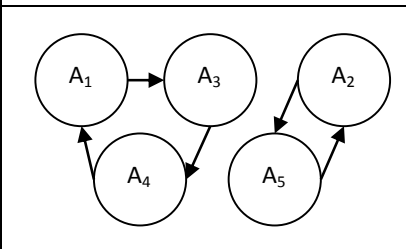
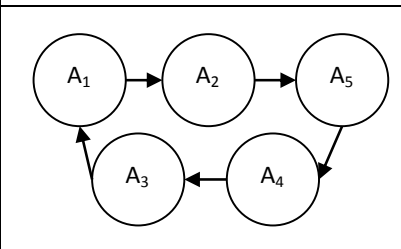
First Group		Second Group	No Term
Third Group	 + 4 more terms	Fourth Group	 + 5 more terms
Fifth Group (a)	 + 3 more terms	Fifth Group (b)	 + 3 more terms
Sixth Group (a)	 + 2 more terms	Sixth Group (b)	 + 1 more term

Figure 3.9.1: Graphs for the permanent multinomial

These sub groups characterise the subsystems of the CIMS(Computer integrated manufacturing system) interrelating in numerous ways and thus backing towards diverse goals of the CIMS(Computer integrated manufacturing system).

3.10 To Identify and compare CIMS structure

For a given system, the total 25 terms of the standard multinomial recognize all possible patterns causative for concerning varying goal of the CIMS and they results as 25 structural tests, that are to be used to analyse the total CIMS in 25 individual patters. Therefore, a

systematic and efficient technique is developed for the structural identification and comparison CIMS.

Comparative study of the computer integrated manufacturing system (CIMS) structure

Due to rise in competition, becomes a necessity to compare the CIMS with the other substituents. Effect of this has long been measured a function of the properties (Skinner, 1969; Hill, 1989; Hayes et all, 1988; Hayes and Wheelwright, 1984; Buffa, 1984) as well as the practiced and follows in numerous structural components of the computer integrated manufacturing (CIM) system and most priory with in the connections. All of these features are presented in the CIMS structure. Therefore, in the terms of permanent function it represents real subsets of the CIM system and is to be used for the comparison of different substitute selections for the CIMS structure. The structure-based comparison is helpful for the development of the new design of the computer integrated manufacturing system. In the field of business, it's a benchmark and restricts which is important modern technology (Jafari et all, 2007). The level of similarity in a systematic method of comparison of CIMS(Computer integrated manufacturing system) structure.

The coefficient of similarity and dissimilarity can be defined by two criteria 1 and 2 by considering the discrete terms in hth subgroup of the gth group of two CIMS permanent function represented by R_{gh} and R'_{gh} , respectively.

Criterion 1. If the difference of the number of terms of the jth subgroup of and ith group of the permanent multinomial, $\phi_{gh} = [R_{gh} - R'_{gh}]$.

Then:

$$\text{Level of dissimilarity, } C_{d-1} = \frac{1}{Y_1} \sum_g \sum_h \phi_{gh}, \quad (3.9)$$

where:

$$Y_1 = \max[\sum_g \sum_h R_{gh} \text{ and } \sum_g \sum_h R'_{gh}]$$

The criterion 1 obtained above, that is moderately simple process of calculating the structural difference between the two computer integrated manufacturing (CIM) systems but this may cause loss of comparative data in the level of dissimilarity.

The structural difference between the two systems in considerations can also result in the negative value of ϕ_{gh} . Results shows, the subtraction processes may be involved and that is a limitation in the level of similarity.

So, a better criterion method can be used by the squares of the comparison values, ϕ_{gh} is established in equation (3.11).

Criterion 2. The level of dissimilarity can be counted by this criterion is given as:

$$C_{d-2} = \left[\frac{1}{Y_2} \sum_g \sum_h \phi_{gh} \right]^{1/2} \quad (3.10)$$

where:

$$Y_2 = \text{maximum} \left[\sum_g \sum_h [R_{gh}]^2 \text{ and } \sum_g \sum_h [R'_{gh}]^2 \right] \text{ and } \phi_{gh} = [R_{gh} - R'_{gh}]$$

As its observed from the equation structure, the value obtained has a dissimilarity between 0 and 1. The coefficient of similarity can be obtained by using the below equation.

$$C_{s-1} = 1 - C_{d-1}, \quad (3.11)$$

$$C_{s-2} = 1 - C_{d-2}, \quad (3.12)$$

where C_{s-1} and C_{s-2} are the numeric value showing level of similarity of two dissimilar computer integrated manufacturing(CIM) systems under observation by criteria 1 and 2, respectively.

The similarities or differences in the above terms replicate any change in the CIMS capacity as permanent function terms being the real subsets of the system are the measure of similarity/dissimilarity performance.

Using the values of the different subsystems, total assessment can be derived. All the value of characters and interactions levels are merged in the permanent function of the CIMS. The numerical as considered by the experts will result into a single numerical score of the total CIMS. The total assessment may be carried out on the basis of the characteristic values for different subsystems. This results into a classified CIMS based on their structures with benchmarks of CIMS.

3.11 Quantification of Factors and Their Interdependencies

The several factors which are affecting the CIMS are acknowledged and listed in table 3.1. Also the subsystems are presented in the same table. Using the table permanent functions presented in each of subsystem Per(P) is evaluated. For this process, the variable function is selected from the lowest order of the table. To avoid complication, an appropriate numeric value is to be allocated at both levels. The numeric value depends on weightage of the

subsystem to the total system. The below table 3.1 suggests that the value which is interdependent of the computer integrated manufacturing system.

S.No.	Qualitative measure of subsystem A_i	Weightage
1	Excellent	6
2	Very good	5
3	Good	4
4	Average	3
5	Poor	2
6	Very poor	1
S.No.	Qualitative measure of interdependencies	Weightage
1	Strong interaction	4
2	Average interaction	3
3	Weak interaction	2
4	Very weak interaction	1

Table 3.11.1: Consists of all Qualitative measure of subsystems and their interdependencies

CHAPTER 4

RESULTS & DISCUSSION

In this study the modeling and analysis of the computer integrated manufacturing system is done using graph theoretical approach. Through various literatures different subsystems and their interactions are identified. Then permanent matrix and the permanent function are developed. The permanent index value can be determined from the permanent function by assigning the numerical values to the subsystems and their interactions. Numerous values of the permanent function value can be obtained by changing one or more parameters. These different values can be used for comparison of system under different conditions.

Important observations obtained under the methodology:

- Different persons can identify different subsystems and their interactions.
- Numerical values of the subsystems and their interactions may vary from expert to expert charged with this task.
- The model developed is theoretical and analysis can be done at the conceptual stage of the development.

Main procedural steps involved in the graph theoretical approach:

1. Identification of various subsystems.
2. Representation of subsystems and their interaction by block diagram.
3. Representation of various subsystems in hierarchical tree structure.
4. Development of graph theoretic models of the system showing subsystems and their interactions.
5. Development of variable matrix and variable function.
6. Development of permanent matrix.
7. Development of permanent function.
8. Structural analysis of the system through terms of the permanent function.
9. Identification of different system for comparison.

4.1 Case Study - I: CIM Database

M. Anwarul (1992) presented the importance of a CIMs database. The definition of CIM is formal connection of all manufacturing operations from the product start and primary

marketing analysis through the design and manufacturing with digital techniques that provide consistency and availability of data to each operation on time. The basic method to the CIM concept is physical and logical integration of design, manufacturing and support systems.

The selection of CIM database is done using Analytic Hierarchy Process (AHP). Basic, general and technical criteria are the classes of hierarchical selection criteria.

The points concluded from the CIM data models are as follows:

- I. There is dissimilarity between various subsystems data. Alphanumeric data is mainly for business system and geometric and graphic for CAD systems.
- II. The sharing of design data is done by various subsystems like CAPP, MRPII and FMS. Interactive Graphic Exchange System (IGES) works as an efficient data conversion tool as design data is not directly recognisable and has to be converted into a recognisable format.

For CAD systems, the data should be dynamically created and deleted for the process. It should also provide information about the tools, equipment capacities etc. Any change in design or data requirement should be automatically updated in the process plan without any constraint.

Geometric data from the CAD is converted in alphanumeric data for MRPII to be used in bill-of-materials (BOM). MRPII database should be updated of any change in the inputs from the CAD and CAPP.

The data characteristics for a common CIM system are as follows:

1. Heterogeneous types of data must be taken care by the CIM database.
2. Integrity constraints and validity checks must be present.
3. Enormous volume of data is required by CAD/CAPP.
4. Sharing of main system data among subsystems should be there.
5. Database has to be made steady at all times by propagating changes in one part to the other part.
6. Apprising must be proficient and fast in order to provide the data as required in real time.
7. Complex objects should be supported by the system.
8. Independence of data must be there for every item.

9. Required data by any system should be instantaneously available for easy access of the operations.
10. The access to the system should be flexible as processing equipment has to support real time operation.
11. Reliability and availability of data should be there for real time operations.
12. Redundancy should be least to avoid any inconsistency in data during real time operations.
13. Same data should not be updated simultaneously by more than one user.

The database requirements meeting these criteria are summarized in figure 4.1.1.

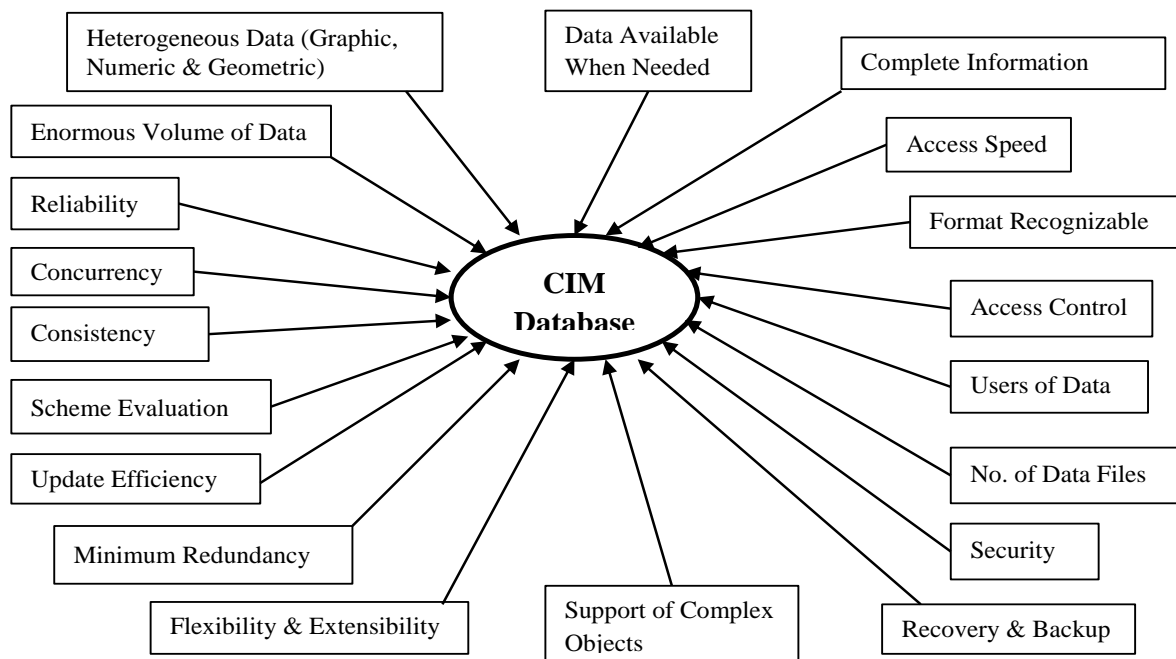


Figure 4.1.1: CIM database requirements

The process of selection is showed in figure 4.1.2 and hierarchy model in figure 4.1.3. The selection process begins with the analysis of database requirement. Using AHP, each alternative is viewed and the decision is thoroughly examined. The AHP model presented in figure 4.1.3. It represents the defined model of selection which emphasise on the three categories and the sub factors of each category.

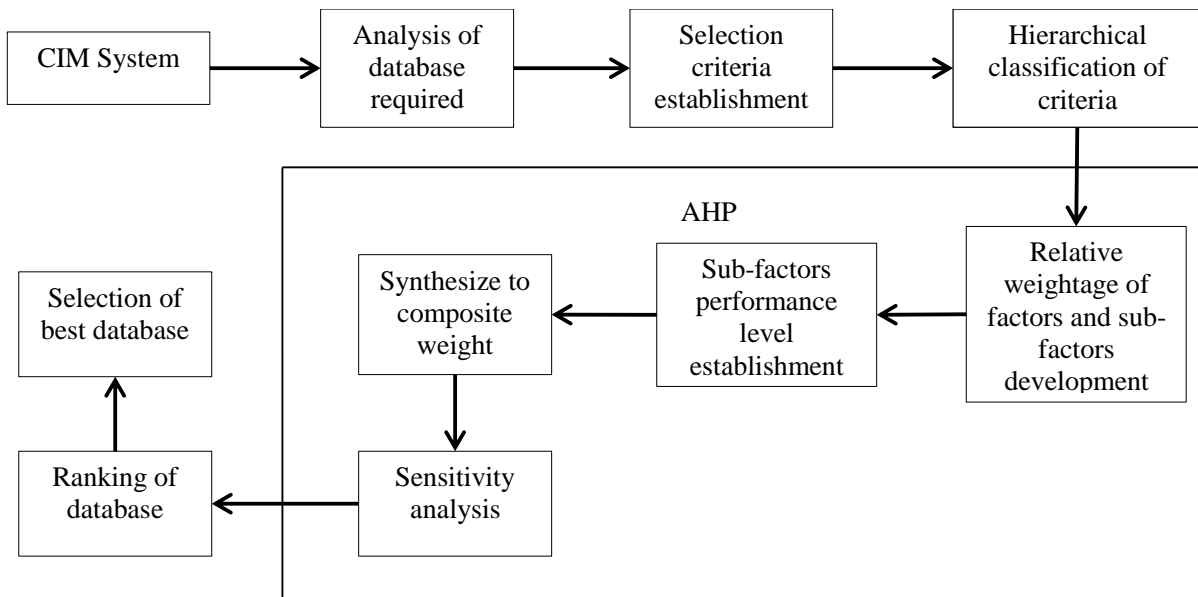
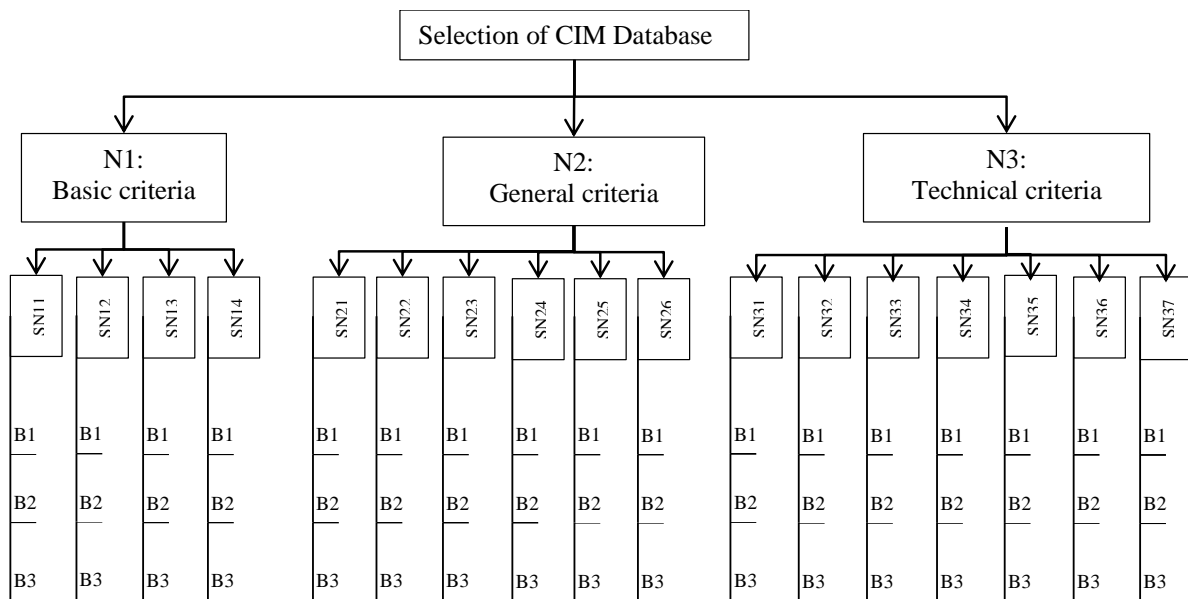


Figure 4.1.2: Database selection model using AHP



- B1: Network database B2: Relation database B3: Object oriented database
 N1: Basic criteria N2: General database criteria N3: Technical criteria relative to CIM
 SN11: Data is to available when needed SN26: Recovery & backup
 SN12: Data have to be complete, not fragmented SN31: Data type
 SN13: Data have to be recognizable format SN32: Access speed
 SN14: The accessibility without intermediaries SN33: Access flexibility
 SN21: Amount of data can be stored SN34: Modularity and extensibility
 SN22: Users of data SN35: Data integrity
 SN23: No. of files required SN36: Update efficiency
 SN24: Access control SN37: Support for complex objects
 SN25: Security

Figure 4.1.3: Hierarchical structure of CIM database selection model

For the selection of a CIM system three types of characteristics must be satisfied by a database:

1. Basic criteria

Easy recovery of complete data information. Data format should be identifiable by all the subsystems for smooth sharing. Easy availability of data for real time operations.

2. General database criteria

Applications in this criteria are common and are of same value. Recovery and backup, no. of users and amount of data are more important criteria than access control, no. of files required and security. This is because heterogeneous software and hardware share huge amount of data.

3. Technical criteria in the context of CIM

The CIM system holds the heterogeneous data types. Data type is of less importance as compared to the access speed for real-time operations. Access speed, extensibility and modularity are important for addition of new entities in the system. Update efficiency is important for reliability of system during real-time operations. Complex objects should be supported.

Diagraph for the technical database developed in fig 4.1.4 contains multinomial of AAA_i and m_{ij} terms. The permanent index can be developed by assigning the numerical values to the subsystems and their interactions. The score obtained will be the numerical value of the subsystem. For subsystem the permanent index of the sub-subsystems will be considered.

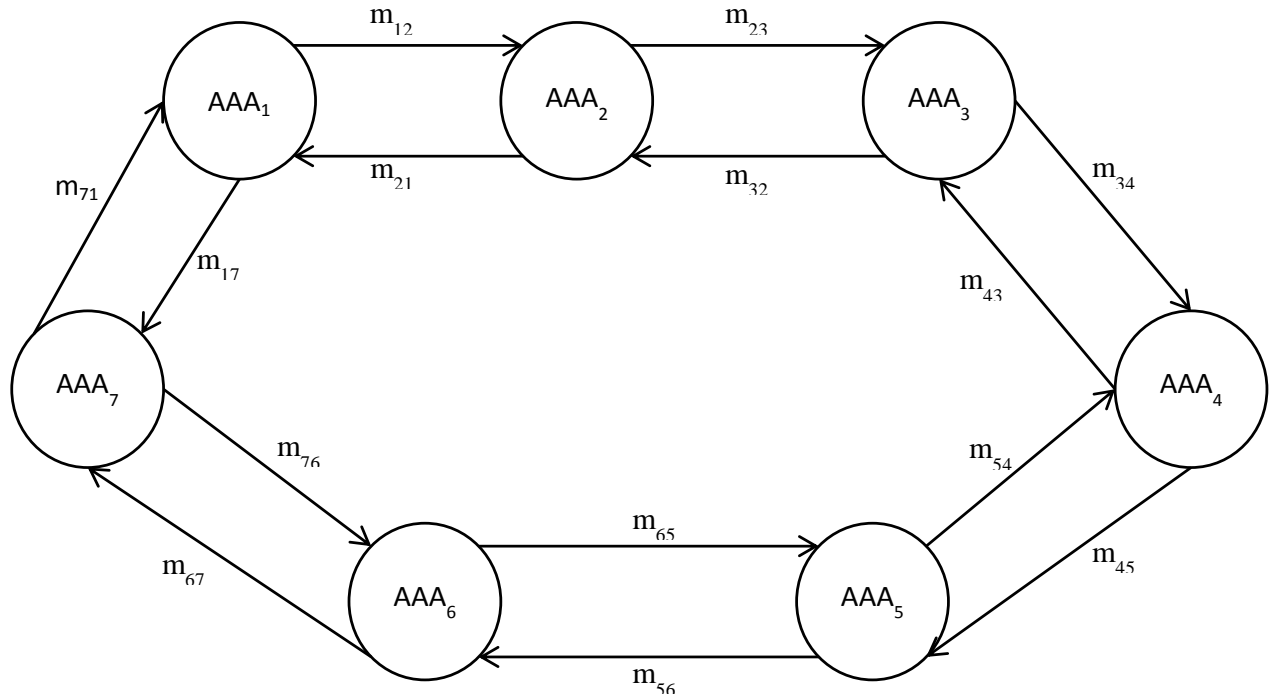


Figure 4.1.4: Diagraph for technical database sub-subsystem

where,

AAA₁: Data type

AAA₂: Access speed

AAA₃: Access flexibility

AAA₄: Modularity and extensibility

AAA₅: Data integrity

AAA₆: Update efficiency

AAA₇: Support for complex objects

The variable permanent matrix for various database criteria can be developed and the numerical value can be calculated. Then the structural graph for the same shown in Fig 3.3 and permanent multinomial can be developed in terms of A_i and m_{ij} .

4.2 Case Study - II: Industrial Automation

4.2.1 Introduction

It is very essential to recognize the structural components, network interface, control parameters and the physical process/application for development of the mathematical model of the industrial automation in a structured way. For this, total five systems have been recognized explicitly; physical process, sensors, network interface, actuators and controller subsystem. These are dependent on the product and the process of automation. The

anticipated methodology is appropriate for modeling a specific industrial automation system and also for the consideration of any variation in structure. The following sections discuss the importance of the identified subsystems.

4.2.2 Physical Process Subsystem

Manufacturing tools, equipments, processes and machines are involved in number of physical process subsystem. Industrial automation design and its specifications depend upon the physical process upto which extent it automates. Martin et al. (1990) made an attempt; In order to reach at a more or less automated manufacturing process optimally matching to an explicit manufacturing problem. In the beginning of the new challenges to design and leane; firms tried a lot to achieve a coherent system to interact between technology, organisation and to meet this challenge. Almannai et al. (2008) established an approach with the usage of both the Quality Function Development (QFD) and Failure Mode and Effects Analysis technique for the supportive management in order to address technology, organisation and people at the beginning stage of decision making in manufacturing automation.

4.2.3 Network Interface Subsystem

To make industrial automation system communicable between subsystems with earliest response time and marvellous flexibility in terms of hardware changeability network interface plays a major role. Replacement of traditional industrial network including some of the technologies like Ethernet switch, real-time operating system kernel etc., with modern network interface conforms the technical trend change to develop framework (hung et al. 2004).

4.2.4 Sensors Subsystem

Sensors produce signal with respect to some physical quantities which help in creating instructions and fluent feedback for the industrial automation system. Their design and specification are very important in respect to detection of quantity and the physical law it governs. Now days for the control applications, the role of sensors is increasing desperately. More acumen and less power consumption in the sensor, reduction through use of extremely integrated microelectronics and microsystems technologies, vigorous measurement methods and a smaller amount installation and wiring costs, enhanced performance (Reininger et al. 2006).

4.2.5 Actuators Subsystem

To move and control of mechanism the mechanical device used is an actuator. It consumes energy usually transported by air, electric current, or liquid, and transforms that into some kind of motion. For the characterization of actuator performance is judged in terms of force, power, current consumption, work output, and efficiency (Plante and Dubowsky 2007). Closed loop functional unit is formed by the sensors and actuators for improving the performance. The future is beyond imagination from sensors and actuators to micro electro mechanical systems (MEMS), to nanofabrication, smart materials and smart structures (Wen 1996).

4.2.6 Controllers Subsystem

Controller delivers an effective and stress-free way to control the categorisation of the actuators movement and the states Industrial Automation system (Swider et al. 2005). As per the guidelines, the designing process involves 3 steps viz. activity analysis, functional design and implementation design for structuring and designing if the Industrial Automation system to better the requirements and capabilities of the controller. The designed controller can perform various functions like welding etc. Any new capabilities can be applied optionally. (Ferretti et al. 1996).

4.2.7 Graph Theoretic Model of the Industrial Automation System

Figure 4.2.7.1 shows the schematic diagram of industrial automation system along with interactions between various subsystems. There are large numbers of applications of systems models using graph theory (Deo 2007) and such models have a solid mathematical background.

Thus, for the modeling of the industrial automation system, a linear graph, H has been defined as a function of vertex set and edge set as $H = f(A,M)$, where A corresponds to a set of vertices $A = \{A_1; A_2; \dots; A_n\}$ and M corresponds to a set of edges $M = \{m_{12}; m_{23}, \dots, m_{mn}\}$ joining different vertices. (Deo, 2000).

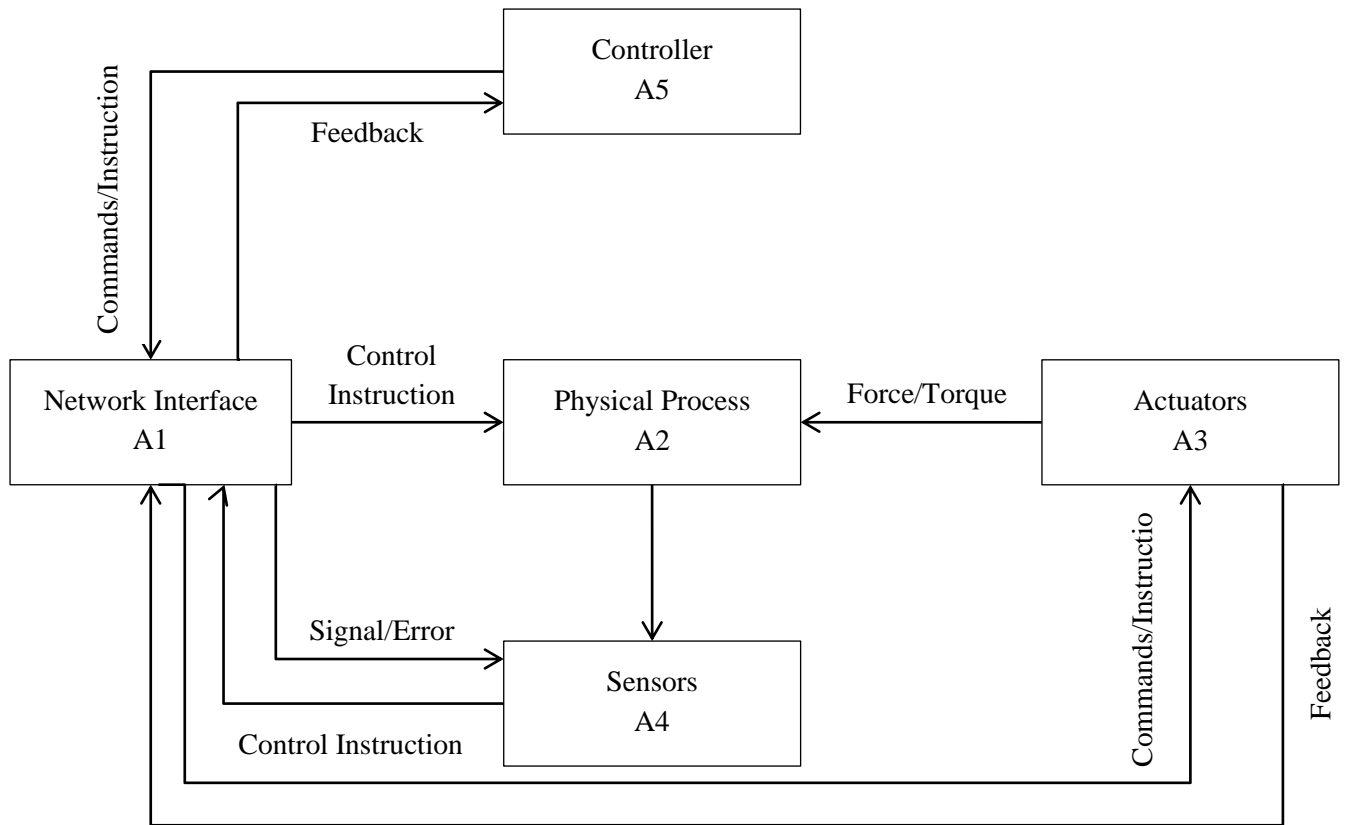


Figure 4.2.7.1: Schematic diagram of industrial automation system

The vertices (A_i) and the edges (m_{ij}) correspond to subsystem and interaction/interdependency respectively. The graph developed for the system is directed graph with interactions specific to the edge direction. The graph is useful mathematical entity and helpful for visual analysis of the system.

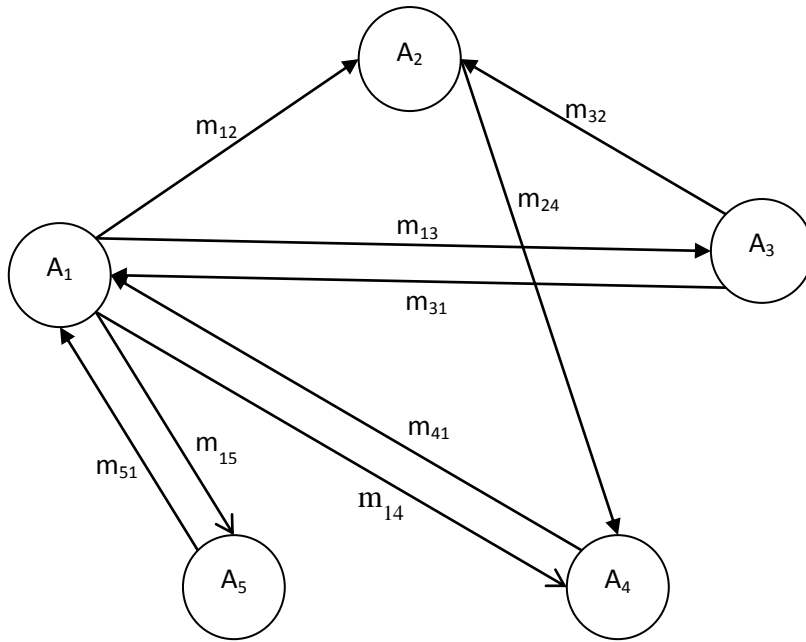


Figure 4.2.7.2: Structural diagram of industrial automation system

4.2.8 Matrix representation for the industrial automation system graph

The graph in the matrix form can be represented by many methods and incidence and adjacency matrices are two of them (Deo 2007). The adjacency matrix is more suitable for the algebraic results as it is a square matrix.

4.2.9 Adjacency matrix

The adjacency matrix with five nodes will be five order binary square matrix, A. The matrix is

$$A = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \text{Subsystems} \\ \begin{matrix} 0 \\ 0 \\ 1 \\ 1 \\ 1 \end{matrix} & \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} & \end{matrix} \quad (4.1)$$

4.2.10 Industrial automation system characteristic matrix

The above matrix only represents the connectivity and not the characteristics of the system. Hence industrial automation system characteristic matrix, B is developed.

	1	2	3	4	5	Subsystems
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$$B = [\lambda I - A] = \begin{bmatrix} \lambda & -1 & -1 & -1 & -1 \\ 0 & \lambda & 0 & -1 & 0 \\ -1 & -1 & \lambda & 0 & 0 \\ -1 & 0 & 0 & \lambda & 0 \\ -1 & 0 & 0 & 0 & \lambda \end{bmatrix} \quad (4.2)$$

The determinant of the matrix is

$$\text{Det}(B) = \lambda^5 + \lambda^3 - \lambda^2 - \lambda \quad (4.3)$$

4.2.11 Industrial Automation System Characteristic and Interdependence Variable Matrix

The characteristic matrix forms the basis of characterisation of the system but fails to distinguish different subsystem and their interactions. To overcome this limitation another matrix called industrial automation subsystem characteristic and interdependence variable matrix (IASSCIVM), C is developed.

For these purpose two square matrices, D & E are defined. D is a diagonal matrix representing different subsystems and E is an off diagonal matrix representing different levels of interactions.

The matrix C is represented as

	1	2	3	4	5	Subsystems
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$$C = [D-E] = \begin{bmatrix} A_1 & -m_{12} & -m_{13} & -m_{14} & -m_{15} \\ 0 & A_2 & 0 & -m_{24} & 0 \\ -m_{31} & -m_{32} & A_3 & 0 & 0 \\ -m_{41} & 0 & 0 & A_4 & 0 \\ -m_{51} & 0 & 0 & 0 & A_5 \end{bmatrix} \quad (4.4)$$

The characteristic features of the subsystems and their interactions are distinctly represented by the above matrix.

The determinant of the matrix C is an invariant of the system.

$$\text{Det}(C) = [A_1A_2A_3A_4A_5] + [-A_2A_4A_5L_{13} + A_2A_3A_4L_{15} - A_2A_3A_5L_{14}] + [-A_3A_5L_{124}] + [-A_5L_{1324}]$$

4.2.12 Composite Performance Index and the Permanent Function

Composite score serves an important role in the total performance analysis. Its numerical value can be obtained by substituting appropriate values of the subsystems and their interactions in the Det(C). In this case because of the subtraction, some of the information may be lost.

The use of permanent matrix and permanent function (Jurkat and Ryser, 1966, Minc, 1966) is proposed to overcome this limitation.

4.2.13 Industrial Automation System Permanent Matrix

The negative sign from the IASSCIVM is removed to obtain the permanent function. The matrix developed is called the industrial automation system characteristic and interdependence variable permanent matrix (IAPSM), P.

$$P = \begin{matrix} & \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \text{Subsystems} \\ \begin{matrix} P = \\ \\ \\ \\ \\ \end{matrix} & \left[\begin{matrix} A_1 & m_{12} & m_{13} & m_{14} & m_{15} \\ 0 & A_2 & 0 & m_{24} & 0 \\ m_{31} & m_{32} & A_3 & 0 & 0 \\ m_{41} & 0 & 0 & A_4 & 0 \\ m_{51} & 0 & 0 & 0 & A_5 \end{matrix} \right] & \end{matrix} \quad (4.5)$$

4.2.14 Industrial Automation System Characteristic and Interdependence Variable Permanent Function

The permanent function has exactly same number and type of terms as in Det(C) with a difference in signs only. It is unique and complete structural representation of the system with advantage of using numerical value.

$$\text{Per}(P) = [A_1A_2A_3A_4A_5] + [A_2A_4A_5L_{13} + A_2A_3A_4L_{15} + A_2A_3A_5L_{14}] + [A_3A_5L_{124}] + [A_5L_{1324}]$$

Structural components of the function are

1. Subsystems

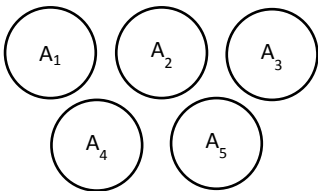
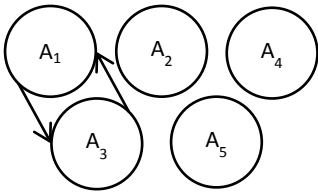
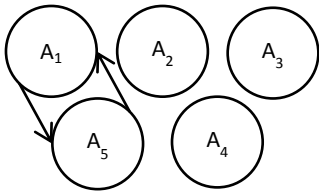
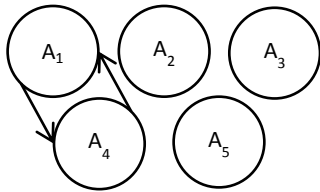
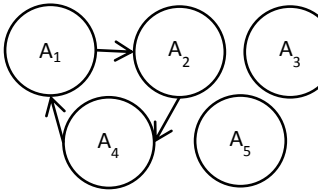
2. Dyads of two subsystems in the form of closed loop, L_{ij} .

3. Closed loops of subsystems, L_{ijk} , L_{ijkl} , L_{ijklm} .

The composite score of the system is obtained by assigning the numerical value to each structural element in the permanent function. There will be $(n+1)$ groups for the n^{th} order permanent matrix.

The characteristic features of all the 6 groups in the matrix are summarised as below:

1. A set of 5 subsystems singularly representing each subsystem comprises of first group.
2. This group doesn't exist as it should have 4 single subsystems and one self-dependent subsystem which is not possible.
3. It comprises of 3 singular subsystems and a 2 subsystem loop.
4. It consists of 2 singular subsystems and a 3 subsystem loop.
5. It comprises of 1 singular subsystem and a set of 4 subsystem loop.
6. This group doesn't exist as it contains a set of 5 subsystem loop.

Group	(a)	(b)	(c)
First Group		No Term	No Term
Second Group	No Term	No Term	No Term
Third Group			
Fourth Group		No Term	No Term

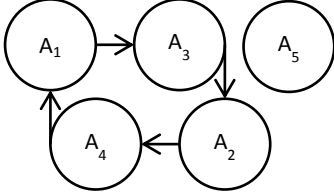
Fifth Group		No Term	No Term
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Figure 4.2.14.1: Graphical representation of the permanent multinomial

4.2.15 Assigning the Numerical Values

Based on different outputs, the numerical values of various subsystems and their interactions can be chosen by the experts in the field studying the behaviour of the system closely.

If the system is complex, then the values can be chosen by decomposing the subsystems further into sub-subsystems.

CHAPTER 5

CONCLUSION

On the basis of methodology, a flexible and comprehensive model has been developed. The developed model has ability to deliberate the interdependencies in between the subsystems of a given system:

- a) The permanent function obtained is helpful in structural analysis of the system as the mathematical model characterising the structure uniquely and various patterns can be identified. This may also serve as an effective method for passing of information regarding the total design.
- b) Permanent index can also be used as a tool for comparison, ranking and selection of CIM system from different provided alternatives. Complex decisions can be analysed using the “what-if” scenarios generated by the index.
- c) Overall performance of the system can be composed by developing various indices of performance in different dimensions like agility, flexibility etc. using this model.
- d) Various structural designs of CIMS can be compared analytically using similarity and dissimilarity coefficients of the individual systems.
- e) All the structural elements of the system are considered in the model which otherwise may not be taken into consideration.

For assignment of numerical values to numerous variables, appropriate procedure and guidelines can be established which will be helpful to the experts.

CHAPTER 6

REFERENCES

- Cleveland, G., Schroeder, R. and Anderson, J. (1989), "A theory of production competence", *Decision Sciences*, Vol. 20, pp. 1987-2007.
- Wiendahl, H.P. and Garfichs, R. (1991) "Trends in computer-integrated manufacturing", *Future Generation Computer Systems*, Vol. 7, pp. 97-107.
- Gandhi, O.P., Agrawal, V.P. and Shishodia, K.S. (1991), "Reliability analysis and evaluation of systems", *Journal of Reliability Engineering and System Safety*, Vol. 32, pp. 283-305.
- Gandhi, O.P. and Agrawal, V.P. (1992), "FMEA-A digraph and matrix approach", *Journal of Reliability Engineering and System Safety*, Vol. 35, pp. 147-158.
- Vickrey, S., Droge, C. and Markland, R. (1993), "Production competence and business strategy: do they affect business performance?", *Decision Sciences*, Vol. 26, pp. 435-55.
- Voss, C. and Blackmon, K. (1994), "Practice performance relationships in UK manufacturing industry", *First International Conference of the European Operations Management Association on Operations Strategy and Performance*, Proceedings of the Conference Held at the Churchill College, Cambridge, pp. 1-6.
- Ward, P.T., Leong, G.K. and Boyer, K.K. (1994), "Manufacturing proactiveness and performance", *Decision Sciences*, Vol. 25 No. 3, pp. 337-58.
- Gandhi, O.P. and Agrawal V.P. (1994), "A digraph approach to system wear evaluation and analysis", *Trans ASME J Tribol*, vol. 116, pp. 268–274.
- Gowan Jr., J.A. and Mathieu, R.G. (1995), "Critical factors in information system development for a flexible manufacturing system", *Computers in Industry*, Vol. 28, pp. 173-183.
- Dowlathshahi, S. (1995), "An integrated manufacturing system design: an applied approach", *Int. J. Production Economics*, Vol. 42, pp. 187-199.
- Bartlett, H. and Harvey, J. (1995), "The modeling and simulation of a pick and place computer-integrated manufacturing (CIM) cell", *Computers in Industry*, Vol. 26, pp. 253-260.

- Gowan Jr., J.A., Mathieu, R.G. (1996), "Critical factors in information system development for a flexible manufacturing system", *Computers in Industry*, Vol. 28, pp. 173-183.
- Shirinzadeh, B. (1996), "Strategies for planning and implementation of flexible fixturing systems in a computer integrated manufacturing environment", *Computers in Industry*, Vol. 30, pp. 175-183.
- Kirsch, C., Strohm, O., Ulich, E. (1996), " Design concepts of computer-aided integrated manufacturing systems: Work-psychological concepts and empirical findings", *International Journal of Industrial Ergonomics*, Vol. 17,pp. 11-19.
- Wang, Z. Y., Rajurkar, K.P. and Kapoor, A.(1996) " Architecture for agile manufacturing and its interface with computer integrated manufacturing", *Journal of Materials Processing Technology*, Vol. 61, pp. 99-103.
- Cheng, K. (1996), "Hypermedia as a tool with application to computer integrated design and manufacturing", *Journal of Materials Processing Technology*, Vol. 61, pp. 143-147.
- Gandhi, O.P. and Agrawal, V.P. (1996), "Failure cause analysis—a structural approach", *Trans ASME J Press Vessel Technol*, vol. 118, pp, 434–440.
- Dreer, P. and Koonce, D.A. (1996), "Integration Extension for Computer Integrated Manufacturing Applications", *Computers ind. Engng*, Vol. 31, No. 1/2, pp. 281 - 284.
- Gunasekaran, A. (1997)," Implementation of computer- integrated manufacturing: a survey of integration and adaptability issues", *International Journal of Computer Integrated Manufacturing*, Vol. 10 No. 1-4, pp. 266-280.
- Islam, M.A., Tabucanon, M.T. and Batanov, D.N. (1997), "Selection of database models for computer integrated manufacturing systems using the Analytic Hierarchy Process", *International Journal of Computer Integrated Manufacturing*, Vol. 10 No. 5, pp. 394-404.
- Goncalves, R.J., Silva, H., Vital, M., Sousa ,P., Garcao, A.S., Teixeira, J.P. (1997), "Implementation of computer integrated manufacturing systems using SIP: Cim case studies using a STEP approach", *International Journal of Computer Integrated Manufacturing*, Vol. 10:1-4, pp. 172-180.
- Mital, A. (1997), "What role for humans in computer integrated manufacturing?", *International Journal of Computer Integrated Manufacturing*, Vol. 10:1-4, pp. 190-198.

- Kokkinaki, A.I., Morse, M.J. (1997), "Case study: Industrial communications architectures and their application in a garment computer integrated manufacturing cell", *Computer Communications*, Vol. 20, pp. 912-922.
- Parks, C.M., Koonce, D.A., Judd, R.P., (1997), "An Integrated Manufacturing Systems Design Environment", *Computers ind. Engg*, Vol. 33, Nos 1-2, pp. 341-344.
- Venkatasamy R. and Agrawal, V.P. (1997), "A digraph approach to quality evaluation of an automotive vehicle", *Quality Engineering*, vol. 9(3), pp. 405–417.
- Sheu, J.J. (1998), "A computer integrated manufacturing system for rotational parts", *International Journal of Computer Integrated Manufacturing*, Vol. 11:6, pp. 534-547.
- Kadipasaoghi, S.N., Hurly, S.F., Foote, J.L. and Khumawala, B.M. (1998), "An investigation of the relationship between global manufacturing practices and outcomes in machine tools and textile industries", *Journal of Operations Management*, Vol. 16, pp. 291-9.
- Samaddar, S., Rabinowitz, G., Mehrez, A. (1999), "Resource sharing and scheduling for cyclic production in a computer-integrated manufacturing cell", *Computers & Industrial Engineering*, Vol. 36, pp. 525-547.
- Cheng, F.T., Shen, E., Deng, J.Y., Nguyen, K. (1999), "Development of a system framework for the computer-integrated manufacturing execution system: A distributed object oriented approach", *International Journal of Computer Integrated Manufacturing*, Vol. 12:5, pp. 384-402.
- Handifield, R. and Nichols, E. (1999), *Introduction to Supply Chain Management*, Prentice-Hall, New York, NY.
- Arora, S. and Kumar, S. (2000), "Reengineering: a focus on enterprise integration", *Interfaces*, Vol. 30 No. 5, pp. 54-71.
- Yin, J.Z. (2002), "Relating learning capability to the success of computer-integrated manufacturing", *Technological Forecasting & Social Change*, Vol. 69, pp. 53–70.
- Choi, K.H., Bae, C.H., Lee, S.H. (2003), "Behaviour modeling and control of computer integrated manufacturing", *International Journal of Computer Integrated Manufacturing*, Vol. 16:2, pp. 128-139.
- Bozdog, C.E., Kahraman, C., Ruan, D. (2003), " Fuzzy group decision making for selection among computer integrated manufacturing systems, *Computers in Industry*, Vol. 51, pp. 13–29.

- Yurdakul, M. (2004), "Selection of computer-integrated manufacturing technologies using a combined analytic hierarchy process and goal programming model", *Robotics and Computer-Integrated Manufacturing*, Vol. 20, pp. 329–340.
- Kahraman, C., Beskese, A., Ruan, D. (2004), "Measuring flexibility of computer integrated manufacturing systems using fuzzy cash flow analysis", *Information Sciences*, Vol. 168, pp. 77–94.
- Grover, S., Agrawal V.P. and Khan, I.A. (2004), "A digraph approach to TQM evaluation of an industry", *International Journal of Production Research*, vol. 42(19), pp. 4031–4053.
- Mohan M., Gandhi O.P. and Agrawal V.P. (2004), "Maintenance strategy for a coal-based steam power plant equipment— a graph theoretic approach", In: *Proceedings of the institution of mechanical engineers- Part A, Journal of Power and Energy*, vol. 218, pp. 619–636.
- Grover, S., Agrawal, V.P., Khan, I.A. (2005), "Human resource performance index in TQM environment", *Int. J. Management Practice*, Vol. 1, No. 2, pp. 131-151.
- Blackhurst, J., Wu, T. and Grady, P.O. (2005), "PCDM: a decision support modeling methodology for supply chain product and process design decisions", *Journal of Operations Management*, Vol. 23, pp. 325-43.
- Prabhakaran, R.T.D., Babu, B.J.C. and Agrawal, V.P. (2006), "Design for 'X'- abilities of RTM products- A graph theoretic approach", *Concurrent Engineering: Research and Applications*, Vol. 14 No. 2, pp. 151-161.
- Sarmiento, R., Byrne, M., Contreras, L.R. and Rich, N. (2007), " Delivery Reliability, manufacturing capabilities and new models of manufacturing efficiency", *Journal of Manufacturing Technology Management*, Vol. 18 No. 4, pp. 129-149.
- Singh, V. and Agrawal, V.P. (2008), "Structural modeling and integrative analysis of manufacturing systems using graph theoretic approach", *Journal of Manufacturing Technology Management*, Vol. 19 No. 7, pp. 844-870.
- Kumar A. and Agrawal V.P. (2008), "Structural modeling and analysis of electroplating system: a graph theoretic system approach", *Int. J. Surface Science and Engineering*, Vol. 2(6), pp.520–540.
- I. Ferrer, I., Rios, J., Ciurana, J. (2009), "An approach to integrate manufacturing process information in part design phases", *Journal of materials processing technology*, Vol. 209, pp. 2085–2091.

- Kumar, A., Clement, S. and Agrawal, V.P. (2010), "Structural modeling and analysis of an effluent treatment process for electroplating—a graph theoretic approach", *Journal of Hazardous Materials*, vol. 179, pp. 748–761.
- Reiter, B.S., Frazzon, E.M., Makuschewitz, T. (2010), "Integrating manufacturing and logistics systems along global supply chains", *CIRP Journal of Manufacturing Science and Technology*, Vol. 2, pp. 216–223.
- Han, T.S., Liao, W.C. (2010), "Computer-integrated manufacturing and high performance work system: the case of Taiwan", *The International Journal of Human Resource Management*, Vol. 21:3, pp. 434-454.
- Jangra K., Grover S. and Aggarwal A. (2010), "Digraph and matrix method for the performance evaluation of carbide compacting die manufactured by wire EDM", *Int J Adv Manuf Technol*, vol. 54, pp. 579–591.
- Kiran, C.P., Clement, S. and Agrawal, V.P. (2011), "Design for 'X'- abilities of a Mechatronic System- A concurrent engineering and graph theoretic approach", *Concurrent Engineering: Research and Applications*, Vol. 19 No. 1, pp. 55-70.
- Ding, G., Jiang, L., Qin, S., Zhu, S. and Ma, S. (2012). "Computer-integrated manufacturing system for tube bending", *International Journal of Computer Integrated Manufacturing*, Vol. 25 No. 11, pp. 1059–1068.
- Tansel, Y. (2012), "An experimental design approach using TOPSIS method for the selection of computer-integrated manufacturing technologies", *Robotics and Computer-Integrated Manufacturing*, Vol. 28, pp. 245–256.
- Ratha, D. and Agrawal, V.P. (2014), "Structural Modeling and Analysis of Water Resources Development and Management System: A Graph Theoretic Approach", *Water Resource Management*, vol. 28, pp. 2981-3003.
- Attri, R., Grover, S. and Dev, N. (2014), "A graph theoretic approach to evaluate the intensity of barriers in the implementation of total productive maintenance (TPM) ", *International Journal of Production Research*, vol. 52:10, pp. 3032-3051.
- Ratha, D. and Agrawal, V.P. (2015), "A digraph permanent approach to evaluation and analysis of integrated watershed management system", *Journal of Hydrology*, vol. 525, pp. 188–196.
- Singh, D., Nigam, S.P., Agrawal, V.P. and Kumar, M. (2016), "Modeling and Analysis of Urban Traffic Noise System Using Algebraic Graph Theoretic Approach", *Australian Acoustical Society*, DOI 10.1007/s40857-016-0058-3.

- Saaty, T.L. (2008), "Decision making with the analytic hierarchy process", *Int. J. Services Sciences*, Vol. 1, No. 1, pp. 83-98.