CHAPTER 2

REVIEW OF LITERATURE

2.1 INTRODUCTION

One of the most significant changes in the global economy over the last two decades is the shift of power, in shaping the market demand from producers to consumers. Consequently, manufacturers are forced to continuously respond to market changes. This requires a manufacturing organisation for the production of a diverse product mix under batch production environment at competitive prices. Meeting this requirement is a big challenge. This can be addressed effectively by the application of the concept of Group Technology (GT) in manufacturing which is often known as Cellular Manufacturing System (CMS) (Gupta and Seifoddini 1990, Chaneski 1998, Seifoddini and Tjahjana 1999).

Credit for pioneering work in the area of GT/CMS is due to Mitrofanov (1966). Manufacturing cells are viewed as more efficient alternatives to the functional departments of the process layout (Burbidge 1971, 1992). The concept of GT has been successfully adopted in the manufacturing systems to derive the composite benefits of job-shop and mass production which seeks to rationalise small-lot production by capitalising on the similarities that exist among component parts and/or processes (Burbidge 1979 Chandrasekaran and Rajagopalan 1986a, Wemmerlov and Hyer 1989, Akturk and Turkcan 2000). The application of GT/CMS requires decomposition of a
large manufacturing system into smaller production systems (cells), representing the basis for advanced manufacturing systems such as JIT, FMS and CIMS. Organisations which adopted GT concepts have realised the benefits of GT (Seifoddini and Wolfe 1986, Wemmerlov and Johnson 1997).

In this chapter, review of literature is presented under the following major areas viz., (i) Traditional cell formation approaches in CMS (ii) Search heuristic methods (iii) Manufacturing focus (iv) Fractional Cell Formation, (v) measures of performance, (vi) Conceptual framework for cell formation approaches, (vii) Comparative studies and (viii) Empirical studies followed by conclusions.

2.2 TRADITIONAL CELL FORMATION APPROACHES

Several researchers have addressed the cell formation problem using different objectives, constraints, input data and solution methodologies (Chu 1995). These approaches are further classified by researchers using different schemes and highlighted the developments and future research directions. Even though schemes are different in certain aspects, the achievements and unresolved issues reported are almost same (Marsh et al. 1999). Based on the approaches used, the traditional cell formation methods are classified into, Classification and coding systems, Array based methods, Cluster analysis, Fuzzy models, Mathematical programming models, graph/network based approaches and other heuristic methods.
2.2.1 Classification and Coding Systems

When GT was in the process of being accepted as a possible solution to the problems of batch manufacturing systems, the emphasis was on the development of part families using Classification and Coding Systems (CCS). CCS is one of the earliest developments in GT that provides general framework. This is an overall approach for integrating the design and production functions.

There were many attempts to devise universal coding systems (Opitz and Weindahl 1971, Knight 1974, Mittal et al. 1988, Bedworth et al. 1991, Luong 1993). Hyer and Wemmerlov (1985) have examined the ways in which coding systems are structured and also described some of the coding systems available in the USA and reported the benefits.

Ham et al. (1988) have developed an integrated approach using Artificial Intelligence (AI) techniques with a provision to include new parts into the part families. A coding system considering empirical requirements for assemblies has been proposed by Mosier and Janaro (1990). Kini et al. (1991) have suggested the use of non significant numbering scheme and a hierarchically significant part numbering scheme. Computerised data base system for classification and coding has been developed by Dangerfield and Morris (1991). GT classification and coding similar to object oriented modeling principles have been developed by Billo and Bidananda (1995). Lin and Horng (1998) have proposed database for sheet metal products based on product pattern using boundary representation method.
Although, the potential benefits of GT are well documented, it is not widely embraced by the manufacturing industry. One of the reasons for this is the difficulties in deciding what to code, in maintaining consistency in the coding process and its interpretation by users (Luong 1993).

Classification and coding systems lack flexibility and cannot adjust themselves to the changes in the product profile over the years. These systems cannot identify parts uniquely and require huge computer memory and human intervention to identify suitable part families which is both time and cost ineffective.

2.2.2 Array based methods

These methods rely on the sorting of rows and columns of the part-machine relationship matrix until some diagonal blocks are formed. This approach has been used by many researchers. In this section some of the array based methods are presented.

A seminal work in the area of GT is production flow analysis (PFA) which is used for grouping of resources at various levels in the organisation. The part-machine relationship is represented as a matrix and then blocks are identified (Burbidge, 1977). In the similar lines, El-Essawy and Torrance (1972) have proposed Component Flow Analysis (CFA).

McCormick et al. (1972) have used bond energy measure to form block diagonals by sorting rows and columns of the matrix. It is reported that it is not suitable as a good performance measure since it is sensitive to the relative positioning of rows and columns i.e., for same value of total bond energy one
can get different solutions and it does not have a finite range and not suitable as a criteria for comparison of the quality of solutions with different dimensions (Nair and Narendran 1997b).

Array based methods have been developed by many researchers using different approaches such as bond energy and shortest spanning path (Slagel et al. 1975), MCIM and its transpose (Bhat and Haupt 1976, Venugopal and Narendran 1993, Nair and Narendran 1997c) and Rank Order Clustering (ROC) (King 1980). Limitations of ROC are revised in ROC2 (King and Nakornchai 1982). Chandrasekharan and Rajagopalan (1986b) have proposed Modified the Rank Order Clustering (MODROC) to overcome many of the limitations of ROC2 while retaining its simplicity. Kusiak (1985) has reviewed sorting based algorithms. Kusiak and Chow (1987a) have proposed Rank Energy Algorithm (REA), which is efficient in computational aspects compared to other algorithms. Algorithm for identification of clusters has been developed by Kusiak and Chow (1987b).

These array based methods do not give the best solution for problems which have exceptional elements. Even a few exceptions are enough to completely misdirect these methods. However, these methods are fast and best suited for problems that do not have exceptional elements. (Nair and Narendran 1997c, 1998).

2.2.3 Cluster Analysis

The identification of machines and component groups is akin to the identification of "clusters" in a scatter of data points. Cluster analysis seeks to group data into clusters such that the elements within a cluster are closely
related while the clusters themselves have little or no relationship amongst them (Anderberg 1973). The major classes of cluster analysis are hierarchical clustering and non-hierarchical clustering where the former is sequential in nature while the later is not. Several researchers have proposed methods based on cluster analysis for cell formation.

The first non-hierarchical clustering algorithm (ideal seed algorithm) for cell formation was developed by Chandrasekaran and Rajagopalan (1986a). The algorithm is based on a modification of the Mac Queen's K-means algorithm. Further refinement of this method resulted in the ZODIAC algorithm (Chandrasekaran and Rajagopalan 1987) and ZODIAC is the best among the existing algorithms for 0-1 data (Miltenburg and Zhang 1991, Kandiller 1994). Srinivasan and Narendran (1991) examined the aspects of selection of seeds and clustering criterion in ZODIAC and developed the GRAFICS algorithm. The production data-based similarity coefficient (Seifoddini and Djassemi 1991) is widely used, since it incorporates various types of production data such as volume, processing time, sequence of operations. Luong (1993) has proposed a clustering algorithm using cellular similarity coefficient between cells and cells are formed by initialising number of cells equal to the number of parts in the system. A two stage clustering algorithm with the objective of minimisation of workload unbalance among the cells is developed by Sarker and Balan (1996).

A clustering algorithm based on Hamming distance metric was developed by Al-Sultan (1997). Nair and Narendran (1998) have proposed non-hierarchical clustering algorithm using sequence data called CASE with association measure computed based on sequence data called bond efficiency. Distance based similarity approach to form cells was proposed by Onwubolu
and Mlilo (1998). Seifoddini and Tjahjana (1999) have proposed a similarity coefficient, called batch size similarity coefficient (BSC) measure considering part volume and batch size and applied to solve an industrial case problem. A bi-criterion approach considering cell load variation and inter cell moves with ordinal and ratio level data was proposed by Nair and Narendran (1999).

The drawback of hierarchical clustering algorithms is due to the choice of threshold value, which has to be made arbitrarily. This has been rectified in non-hierarchical clustering algorithms. The approaches under non-hierarchical clustering category do not make explicit use of intrinsic properties (similarities) between machines. The final solution depends on the initial choice of seeds. It is implicitly assumed that if there exist some natural group of these machines they will eventually appear in the final solution.

2.2.4 Fuzzy models

Models under this category are based on fuzzy set theory. Fuzzy sets allow elements to be partially in a set. Each element is given a degree of membership in a set and range from zero to one. These models are suitable for dealing with impreciseness that exist in the parameters of any system.

A few researchers have used fuzzy approach for cell formation. The concept of fuzzy graph theory in the form of cliques to form cells in CMS has been used by Rajagopalan and Batra (1975). Xu and Wang (1989) have proposed fuzzy mathematics for part family formation using different membership functions. Chu and Hayya (1991) have presented a fuzzy C-means clustering algorithm and studied the impact of parameters in fuzzy clustering process.
Fuzziness in part-features and machining processes are quantified by Ben_Arieh and Triantaphyllou (1992). Zhang and Wang (1992) have proposed a fuzzified similarity coefficient considering part requirements and machine capabilities. Gindy et al. (1995) have extended the fuzzy C-means clustering algorithm by incorporating clusters centroids and also proposed a validity measure based on cluster compactness and machine repetition factors and applied the model to solve a real life problem consisting of around 10000 components.

Tsai et al. (1997) have proposed a fuzzy mixed integer programming (FMIP) model using a new fuzzy operator. Shanker and Vrat (1999) have developed a fuzzy LP model for the design of CMS at the post clustering stage to handle uncertainty in the form of linguistic vagueness. Lee et al. (1998) have developed software for cost estimation integrating neural network and cluster analysis. Choobineh and Nare (1999) have proposed Rough Set theory concept using both manufacturing and non-manufacturing information of parts.

The degree of fuzziness has to be chosen with extreme care as a large value may confound the analysis. This is an inherent limitation of fuzzy based approaches.

### 2.2.5 Mathematical programming models

Several researchers have developed mathematical models for cell formation using different objectives. These include (i) Similarity coefficient, (ii) Cost based and (iii) Operation related (Chu 1995). These models are solved using optimal and/or heuristic methods (Singh 1993). A general frame work has been provided by Selim et al. (1998) considering real life aspects as multi-
objective/ uni-objective (Dahel and Smith 1993) with more meaningful constraints. Most of the models suffer from drawbacks such as integration of different stages, multiple units of machines, alternate part routeings etc. A comprehensive review of these models has been presented by Chu (1995).


Models based on cost data have been developed by Panneerselvam and Balasubramanian (1985), Choobineh (1988), Fraizer and Gaither (1991), Wei and Gaither (1990), Shafer and Rogers (1991), Shafer et al. (1992), Logendran (1992), Rajamani et al. (1990, 1992, 1996), Adil et al. (1993), Sankaran and Kasilingam (1993), Logendran and Ramakrishna (1995), Zhu et al. (1995) and Cheng et al. (1996). In these models the cost of resources, cost of inter and intra cell moves and other related costs are assumed due to difficulties in estimating exact costs. Heuristic methods have been proposed to solve the models.
Operation related measures such as minimisation of total inter cell movements, intra cell movements, number of exceptional movements, machine hours, load variation, cell utilisation, operator skills etc., have been used to form cells in CMS environment. Models under this category have been developed by Han and Ham (1986), Kusiak and Cheng (1990), Nagi et al. (1990), Sankaran (1990), Logendren (1990, 1991), Boctor (1991), Singh et al. (1992), Venugopal and Narendran (1992a, 1992b), Ng (1993, 1996), Chow and Hawaleshka (1993), Arvind and Irani (1994), Liang and Taboun (1995), Adil et al. (1996), Heragu and Chen (1998), Shang and Tadikamalla (1998), Cao and McKnew (1998) and Mehrotra and Trick (1998).

Ballakur and Steudel (1987) have developed a dynamic programming model for cell formation with an objective to maximise within cell utilisation. Logendran (1990) has developed a model considering both inter cell and intra cell moves and solved the model using heuristic approach. Logendran (1991) has considered sequence of operations and the impact of layout of cells in evaluating both inter cell and intra cell moves. LPP model for selection of routes proposed and cells are formed by bottom-up aggregation procedure (Nagi et al. 1990). A multiple objective model for cell formation problem and a heuristic approach has been proposed by Sankaran (1990).

Ng (1993) has viewed cell formation problem as an equivalent portion of travelling sales man problem and solved with bond energy objective and proposed worst case bound. An integer programming (IP) model for minimisation of exceptions has been proposed by Boctor (1991). Singh et al. (1992) presented a bi-criteria framework for operations assignment in CMS for minimisation of total processing cost and total processing time and balancing of workloads. Chow and Hawaleshka (1993) have proposed a heuristic procedure to minimise inter cell moves using binary data. Arvind and Irani
(1994) have proposed a mixed integer programming (MIP) model for cell design and layout problem. Liang and Taboun (1995) have presented a non-linear integer model with bi-criteria approach.

Adil et al. (1996) have developed a quadratic model to form cells with alternate process plans and multiple copies of machine type for minimisation of weighted sum of exceptional elements and voids within the diagonal blocks. Shang and Tadikamalla (1998) proposed a multicriteria approach for robust and optimal design/control of CMS using Taguchi experiments and response surface methodology. An optimal MIP model for CMS design has been proposed and solved using Benders’ decomposition by Heragu and Chen (1998). Cao and McKnew (1998) have proposed a partial termination rule of Lagrangian relaxation for cell formation problems. Mehrotra and Trick (1998) have proposed capacitated and uncapacitated models for cell formation and solved using branch and price method.

Despite many benefits of optimal methods, it faces the dimensionality problem, because as problem size increases computational load intensifies. Further, many models require the number of cells as a priori (Kusiak 1987, Viswanathan 1996) which is very difficult to specify. However, many research issues raised in early reviews remain largely unexplored (Chu 1995).

The cell formation problem has been shown to be a hard problem and there is no algorithm that exist which can solve large size real life problems optimally in polynomial time (Murthy and Srinivasan 1995). Further it is reported that scholars are no longer in touch with the real-world problems encountered in industry. Instead, they are guided towards problems that can take advantage of their mathematical skills (Marsh et al. 1999, Wemmerlov and Johnson 2000).
2.2.6 Graph /Network based approaches

The methods under this category make use of the theoretical foundations of graph and network theory for analysing the cell formation problem with suitable representation of parts and machines relationship.

Rajagopalan and Batra (1975) have introduced the concept of graph and fuzzy set theory to form cells. Faber and Carter (1986) have represented the problem as a network and decomposed the network into sub-graphs. Chandrasekaran and Rajagopalan (1986a) have proposed an ideal seed non-hierarchical clustering algorithm based on bipartite graph approach. Minimal-cut theory concept has been used to handle bottleneck machines and parts in CMS by Vannelli and Kumar (1986). Ballakur and Steudel (1987) and Kusiak and Chow (1987a) have developed graph searching algorithms based on key machine/part concept. Askin and Chiu (1990) have proposed a cost based graph theory formulation for GT configuration using Kernighan and Lin (1970) algorithm. Vohra et al. (1990) have proposed a non-heuristic network approach for minimisation of inter cell moves. Askin et al. (1991) have used Hamiltonian path approach with a distance based similarity coefficient.

Srinivasan (1994) has proposed minimal spanning tree (MST) approach to develop seeds from which cells are formed. Srivastava and Chen (1995) have proposed a quadratic programming model and solved using graph partitioning algorithm. Veeramani and Mani (1996) have described a polynomial time algorithm based on a graph theoretic approach. Hadley (1996) has proposed a graph partitioning technique for minimisation of machine duplication cost and part sub-contracting cost.
Wu and Salvendy (1993) have proposed a modified network approach for cell formation. Wu (1998) has represented the problem as undirected graph and solved it by applying minimum cut-set theory. Wu and Salvendy (1999) have proposed a new graphical model for cell formation problem with multiple copies of machine type and solved using merging and breaking heuristic method.

These approaches require the problem to be specified in the form of graph/network and the network so constructed will be decomposed into small networks. This is done based on cost or non cost and other related measures such that the cells are more autonomous. However specifying such a criteria and decomposition depends on the size of the problem and representation and further it is not possible to find acceptable solutions in most of the cases.

2.2.7 Other heuristic methods

Several other heuristic approaches have been applied in CMS design. Waghodekar and Sahu (1984) have proposed an algorithm called MACE (MAchine component CEll formation) to solve the GT problem using three types of similarity coefficients (additive, product and total). Panneerselvam and Balasubramanian (1985) have addressed a flow line type cell formation considering sequence, production volume with an objective of minimisation of total cost of MH and idle capacity of machines using Ignizio’s covering technique.

Askin and Subramanian (1987) have developed a cost based model for minimisation of inter cell cost. The model forms cells based on routing similarity. Khator and Irani (1987) have proposed occupancy value method by
considering machine usage. Harhalakis et al. (1990) have presented a two fold heuristic procedure capable of minimising inter cell material movement by considering sequence of operations.

Kusiak (1991) has developed three heuristic procedures with bottleneck parts and machines using cluster identification algorithm. Kang and Wemmerlov (1993) have developed a workload based heuristic approach with a feature of reallocation of operations to alternative machines while meeting capacity constraints. Balasubramanian and Panneerselvam (1993) have proposed a covering technique based algorithm using sequence similarity and formed cells for economic production. The algorithm identifies machine arrangement within the cell. The algorithm addresses the total facilities design problem including machine grouping, cell loading and estimation of machine requirements and effect of idle time and over time of the machines. Waghodekar (1996) has developed heuristic procedure called MOMACE which is a modified version of MACE (Waghodekar and Sahu 1984).

Lin et al. (1996) have proposed a hybrid heuristic to form cells with an objective to minimise cost due to cell imbalance, inter cell and intra cell processing costs and applied to an industrial case. From the case study it has been noted that only part of the total resources are formed into cells and the rest have been kept as a small job shop like cell. Beaulieu et al. (1997) have considered the machine selection problem for the design of new CMS. This method considers machine capacity, alternative routing and cell size constraints.

Lee and Chen (1997) have developed a three phase heuristic approach to solve cell formation problem. The procedure considers cycle demand, batch
size, pallet size, routing sequence, processing times, machine capacities and workload status of the machines. Heragu and Kakuturi (1997) have proposed a three stage heuristic approach, incorporating material flow considerations with alternative process plans for grouping and placement of cells.

Vakharia and Chang (1997) have proposed a combinatorial search algorithm based on simulated annealing and Tabu search concept. The performance of the algorithm is evaluated using randomly generated problems and industrial data. It is found that SA is most suitable for CMS cell design problems and can identify near optimal solutions. Akturk and Turkcan (2000) have addressed cell formation and layout problems simultaneously using a holonistic approach to maximise profit of overall system and also individual cells.

These methods often lead to sub-optimal solutions with suitable parameters.

2.3 SEARCH HEURISTIC METHODS

Due to combinatorial nature of cell formation problem, several researchers have developed algorithms based on combinatorial optimisation search techniques such as Genetic Algorithms (GA), Simulated Annealing (SA), Tabu Search (TS), Neural Networks (NN), Expert Systems (ES) and Artificial Intelligence (AI). These methods have been used extensively to find near optimal solution for multi-objective cell formation problems.

Genetic Algorithm (GA) is a computerized search and optimisation algorithm based on the mechanics of natural genetics and natural selection.
(Goldberg 1989). GA attempts to mimic the biological evolution process for discovering good solutions.

A solution procedure based on GA for cell formation with multiple objectives has been developed by Venugopal and Narendran (1992b). Gupta et al. (1996) have used GA based solution to address the cell formation problem using sequence and time requirement for each operation with an objective of minimisation of inter cell and intra cell moves, minimisation of cell load variation and minimisation of both.

Hsu and Su (1998) have proposed a GA based solution procedure for CMS design using inter cell and intra cell part transport factor, machine investment cost, intra cell load imbalance and inter cell load imbalance. Lee-Post (2000) has proposed a simple genetic algorithm considering part geometry attributes (coding information) and manufacturing attributes and applied to an industrial case.

Simulated Annealing (SA) based heuristic procedures have been used in CMS design problem by several researchers. Harhalakis et al. (1990) have developed SA based procedure for the design of manufacturing cells for minimising the inter cell traffic with cell size constraint and tested the procedure through an industrial case. Venugopal and Narendran (1992a) have proposed SA algorithm considering several real life factors such as processing time, volume of components, capacity of machine etc. Simulated annealing procedure has been proposed for cell formation and layout of cells using preemptive goal programming by Bazargan and Kaebernick (1997).
Sofianopoulou (1997) has proposed a mathematical model to form cells and developed SA approach to solve large size problems. Zolfagari and Liang (1998) have proposed a SA based approach for machine cell formation considering processing times and machine capacities using neural network approach to provide a seed solution. Su and Hsu (1998) have proposed parallel simulated annealing algorithm considering inter cell and intra cell part transportation cost, machine investment cost, intra cell machine load unbalance and inter cell machine load unbalance. Nambirajan and Panneerselvam (1999) have developed a SA based algorithm for cell formation using binary data.

Logendran *et al.* (1994) have proposed an approach based on Tabu Search for the design of CMS with alternate process plans. Vakharia and Chang (1997) have developed two heuristic methods based on SA and Tabu Search for cell formation problem. Baykasoglu and Gindy (2000) have proposed a pre-empitive goal programming model with multiple objectives (MOCACEF 1.0) and Tabu Search has been used to obtain solution considering resource elements requirements.

The Neural Network (NN) approach has been the subject of intensive study by interdisciplinary researchers for a long time. Research in this area is still in the early stages and these have been classified based on type of input, the learning mode (supervised/unsupervised) and type of models used (ART, SOFM, Hopfield etc) (Venugopal 1999).

Malve and Ramachandran (1991) have proposed an unsupervised NN model based on competitive learning for cell formation and compared with classical clustering techniques. Chu (1993) has implemented the basic competitive learning model using standard software and reported that the
success rate of the network as 89%. Venugopal and Narendran (1994) have developed NN model using basic competitive learning and trained the network using permuted training concept. Malakooti and Yang (1995) have modified the competitive algorithm by using the generalised Euclidean distance and a momentum term in the weight vector to improve the stability of the network.

The Competitive Learning (CL) topology has minor deficiencies with respect to the learning stability and is very sensitive to the learning rate. The model appears to force an assignment even if no appropriate group exists instead of indicating the need for a new group for significantly different parts/machines. This model has simpler structure than many other unsupervised learning paradigms.

The application of the interactive activation model to the part-machine grouping problem has been investigated by Moon and Chi (1992), Currie (1992) and others. The use and performance of this model for grouping is not clearly brought out in the literature.

Lee et al. (1992), Venugopal and Narendran (1994), Rao and Gu (1994) have proposed models using Self Organising Feature Map/Model (SOFM) for cell formation. Venugopal and Narendran (1994) have tried with small size problems. Kiang et al. (1995) and Kulkarni and Kiang (1995) have also developed models using SOFM for cell formation using sequence similarity as input to the network. SOFM models have flexibility of deciding and fixing the number of groups. The major problem with this model is the time required to train the network.
Adaptive Resonance Theory model (ART-1) accepts only binary data and consists of two layers, input and output. This model with vigilance parameter which induces reset of a node and the weight updating procedures is different from competitive model and SOFM model.

Kaparthi and Suresh (1992) have investigated the capabilities of ART-1 with large size data sets generated randomly and found that the ART-1 models can identify groups relatively fast with a good degree of perfection. The performance of the ART-1 model could be improved by reversing zeros and ones in the matrix (Kaparthi et al. 1993). Rao and Gu (1995) have observed that many of the NN applications to the cell formation problem ignored many constraints that may exist during the cell design process. Chen and Cheng (1995) have indicated that the quality of the solution given by ART-1 depends on the initial disposition of the matrix. They have proposed supplementary procedure to eliminate this problem.

Various drawbacks in the application of ART-1 model are (i) the number of patterns required to store grow faster as more input vectors are applied, (ii) the classification process and the result are completely dependent on the order in which the input vectors are applied and (iii) the quality of the solution depends on the choice of the vigilance parameters.

Fuzzy ART model is an improvement over ART-1, in which the network accepts fuzzy logic into ART based neural networks. It is stable and suitable for both binary and non-binary input patterns. Fuzzy ART model has been employed for cell formation by Suresh and Kaparthi (1994), Kaparthi and Suresh (1994), Suresh et al. (1995), Kamal and Burke (1996) have introduced FACT, which is an improved version of fuzzy ART model. From various
studies it is found that the application of fuzzy ART with the fast learn/slow recode option overcomes the problem of category proliferation at least in some cases. However, fuzzy ART also suffers from the choice of parameter.

Kao and Moon (1991) have developed a procedure using feed forward neural network with back propagation learning rule to generate part code and part families simultaneously. Jamal (1993) have proposed a model using back propagation concept and it was found that the efficiency of the network depends on the number and type of examples with which the network is trained. Kao and Moon (1998) have proposed a new approach using feature-based memory association of NNs. Cells are formed using part, features and machines without routeing sheets. However all part features are considered equally.

Deterministic neural network models do not have the capability to escape from the local optimal solution. Stochastic NN models avoid converging to the local optimal solution. However, specification of the values for stochastic models is more complicated than the deterministic models. Arizono et al. (1995) have developed recurrent neural network model to solve grouping problems in FMS environment by proposing a suitable 0-1 IP model.

Artificial Intelligence (AI) and pattern recognition are relatively new tools used for GT problem and not much work is reported so far.

Kusiak (1988) has developed a knowledge-based system, which takes advantage of expert system and uses user's production expertise. Wu et al. (1986) have proposed a syntactic pattern recognition approach using distance measure considering material flow in the cell.
From the past studies, it is found that these methods are more promising tools for combinatorial problems. It is possible to obtain near optimal solutions by careful selection of parameters with affordable computational time.

2.4 FOCUSED MANUFACTURING

The concept of focused manufacturing is based on the observed need to match competitive priorities with the manufacturing process and limiting the set of products, technologies, volumes and markets for which a plant is responsible. The resulting simplicity and consistency of the manufacturing system can enhance the firm's competitive position in the market. When an individual plant has to resolve conflicts among multiple competitive dimensions or markets served, Skinner (1974) suggests a plant-within-a-plant (PWP) system in which the existing facility is divided both organizationally and physically. Each PWP has its own facilities in which it can concentrate on its particular task. Hayes and Wheelwright (1984), Hill (1994) and Schonberger (1990) each one support Skinner's concept of developing focused manufacturing units within a plant whenever a single plant must serve multiple markets. Despite the potential benefits of plant within a plant (PWP) design, the research on implementing such a design is very limited (Sheu and Krajewski 1996).

Fine and Hax (1985) has identified strategic product groups of a firm by making subjective judgements regarding the positioning of various product lines in the product-process matrix. Berry et al. (1991) have proposed an analytical approach in formulating PWPs wherein a clustering analysis was used to form focused product groups or PWP. The methodology was tested using real data from three organisations. Hill (1994) used percentage weights for the order-winner criteria of every product and grouped the products having
high weights on the common order-winning criteria but no formal method has been developed.

The focused factory based system is really a form of CMS. This concept is widely used in the electronics industry. The focus factory based system is highly efficient but lacks flexibility to handle the varieties of products and dynamic changes in customer demands and it may create load imbalance problem or under utilisation of resources etc. The load imbalance problem can be solved by machine duplication but most of the companies will not choose this alternative due to high investment cost and/or under utilisation of resources, space constraints etc (Liao 1994). Liao (1994) has proposed a three-stage procedure for design of focused CMS for solving load imbalance problem and proposed a suitable layout of cells using facility layout module of STORM.

Sheu and Krajewski (1996) have developed a mathematical model and a heuristic for developing PWP's with competitive priorities and volume as surrogates for manufacturing focus. The heuristic translates the strategic concept of competitive priorities into management parameters, thereby allowing incorporation of market factors into manufacturing process design.

However, the concept has not been adopted widely by industries and not researched to the extent required. In summary, all these studies recognise the difficulties in formulating a suitable model and solution procedure for implementing the focused manufacturing concept. Most of the above studies have considered the processing requirements and current practices that are being used by the organisations trying to meet the customer needs and organising the manufacturing setup to achieve this objective.
2.5 FRACTIONAL CELL FORMATION

The idea of fractional cells has been mentioned in the GT literature by Burbidge (1977) and Greene and Sadowski (1983). However, there has been very limited research reported in this area. Inter cell moves among manufacturing cells in the system can be reduced to a large extent by constituting a remainder cell with machines that process parts of more than one family. In Fractional Cell Formation (FCF), components are allowed to undergo processing in GT cells and a remainder cell (if required), but not in other GT cells (Murthy and Srinivasan 1995).

FCF approach would be viable because, most of the cellular manufacturing applications are used to produce only a small percentage (10%) of the total parts in the shop. Typically parts having characteristics conducive to cellular manufacturing are produced in cells, the remaining are produced in a job shop environment (Wemmerlov and Hyer 1989).

Seiffodinni (1992) has addressed the hybrid cell formation problem, in which the system consisting of cells with non-bottleneck machines and a cell with the bottleneck machines. This is arrived at by applying a performance measure that reflects inter cell material handling. The hybrid cell is arrived at after application of the clustering algorithm to form cells. Later the bottleneck machines are arranged as a hybrid cell. Performance of the CMS with and without hybrid cell is compared and found that the CMS with hybrid cell results in higher inter cell material handling cost. This may be due to incorrect identification of hybrid cell composition i.e., cells are not formed with the objective minimisation of inter cell moves.
Murthy and Srinivasan (1995) have addressed the cell formation problem using the concept of exclusive remainder cell for the requirements of bottleneck parts from other cells. This is the first formal study that addressed the issue of fractional cells. The authors have developed a mathematical model with the objective of minimisation of inter cell moves among GT/manufacturing cells. Solution methodology is proposed based on SA concept and solved large size problems from the literature limited to binary data.

Subsequently, Srinivasan and Zimmers (1998) have addressed this problem with the objective minimisation of both inter cell moves and remainder cell moves in the system. They have developed two algorithms that generate solutions with less and moderate computational time. Their study has addressed the fractional cell formation problem with minimisation of inter cell moves, total moves and weighted sum of inter cell and remainder cell moves. The results obtained by these algorithms are compared using large size real life matrices in the form of binary data. Castillo and Suer (2000) have developed a clustering procedure to determine when a line should be dedicated to a single part. The algorithm developed identifies, dedicated cells for the products with adequate volume, manufacturing cells for the parts which do not satisfy the first criterion otherwise a remainder cell for the parts which do not fit any of these cells.

From this limited research in the area of FCF, there is an immense need to address this problem using different types of data and relevant constraints.
2.6 MEASURES OF PERFORMANCE

A flood of methods to solve the problem of design of CMS raises a few vital questions such as

(i) How does the analyst choose a method?
(ii) How does the analyst evaluate the results?

These have necessitated the development of performance measures. The goodness of the solution/method can be evaluated on the basis of effectiveness and/or computational efficiency.

2.6.1 Performance measures for binary data

Most commonly used performance measures to evaluate the goodness of the cell formation algorithms or solutions are Percentage of Exceptional Elements (PEE), Machine Utilisation (MU), grouping efficiency, grouping efficacy and grouping index.

King (1980) and Chan and Milner (1982) have recommended the use of Percentage of exceptional elements (PEE) which is defined as the ratio of the number of exceptions (e₀) and the total number of 1’s in the Machine Component Incidence Matrix (MCIM) (e) [PEE = (e₀/e)] to measure the quality of clustering. A small value of PEE indicates a better solution.

Chandrasekaran and Rajagopalan (1986a) have defined Machine Utilisation (MU) as the ratio of the number of ones within the diagonal blocks to the total number of elements (both zeroes and ones) in it. A high value of
MU indicates a better solution. It does not consider the exceptional elements outside the block diagonals.

Grouping Efficiency (GE) ($\eta$) is the weighted average of two functions $\eta_1$ and $\eta_2$ (Chandrasekharan and Rajagopalan 1986b).

$$\eta = q \ast \eta_1 + (1-q) \ast \eta_2$$  \hspace{1cm} (2.1)

where,

$$\eta_1 = \frac{\text{Number of ones in the diagonal blocks}}{\text{Total Number of elements in the diagonal blocks}}$$ \hspace{1cm} (2.2)

$$\eta_2 = \frac{\text{Number of ones in the off-diagonal blocks}}{\text{Total Number of elements in the off-diagonal blocks}}$$ \hspace{1cm} (2.3)

and $q$ is a weighting factor ($0 \leq q \leq 1$), and is assumed as 0.5.

Although the function has the properties of non-negativity and zero-to-one range, its discriminating power is weak. For large matrices and/or sparse matrices to have equal weights for voids and exceptional elements, it is necessary to choose a low value for 'q' (Nair and Narendran 1996).

Further, to use this as an objective function for maximisation, it requires weightage ($q$) for voids and exceptional elements. Solutions with highest GE need not correspond to the more satisfactory solution since the ratio of non-zero elements in the off-diagonal and zero elements in the diagonal are different. In case of sparse matrix, the ratio of 0s and 1s is much smaller. This ratio may not relate the relative importance of the inter cell cost and the intra cell cost. Choosing a smaller value for 'q' need not make the situation better for
some problems. Due to high value of GE it is very difficult to distinguish between well-structured and ill-structured data sets (Islam and Sarker 2000).

Kumar and Chandrasekharan (1989) have proposed a measure called Grouping Efficacy ($\tau$). A high value of efficacy indicates good performance.

$$\tau = \frac{(1-\psi)}{(1-\varphi)} \quad (2.4)$$

where

$$\psi = \frac{\text{Number of exceptional elements}}{\text{Total Number of operations}} \quad (2.5)$$

$$\varphi = \frac{\text{Number of voids in the diagonal blocks}}{\text{Total Number of operations}} \quad (2.6)$$

Sandbothe (1998) has examined the effect of illogical part/machine assignment and reassignment of parts and machines on grouping efficacy. Upper and lower bounds are developed for voids and exceptions. Grouping efficacy can increase only when the exceptions/voids fall within this bound.

Grouping efficiency and efficacy measure assigns unequal weights to the voids and exceptions, unknown to the user. The weights for voids are more than that for exceptions and the user does not have the freedom to assign weights for voids and exceptions depending on the situation.

To overcome the deficiencies of grouping efficiency and efficacy, Nair and Narendran (1996) have developed the measure, Grouping Index ($\gamma$), incorporating the block diagonal space, weighting factor and correction factor,
\[ \gamma = \frac{1 - \left\{ q e_v + (1-q) \left( e_0 - A \right) \right\} / B}{1 + \left\{ q e_v + (1-q) \left( e_0 - A \right) \right\} / B} \]  

where,

- \( e \) = Total number of operations (No. of ones)
- \( e_v \) = Block Diagonal Voids
- \( e_o \) = Exceptions
- \( B \) = Space
- \( q \) = Weightage factor
- \( A \) = Correction factor
- \( A = 0 \) for \( e_o \leq B \)
- \( A = e_o - B \) for \( e_o \geq B \)

Chandrasekaran and Rajagopalan (1989) have studied the characteristics of binary data on the solution quality. Groupability is a function of number of machines (m), number of parts (p), number of operations (e) in the matrix and the mean and variance of the Jaccard's similarity coefficient for row (parts) and column (machine) vectors. It is concluded that the matrices with Jaccard's similarity value outside the range of 0.25 to 0.35 can be rejected as unsuitable for grouping.

### 2.6.2 Performance measures for other data

Sarker and Li (1998) have developed a performance measure using alternate routings for parts which is known as ARG Efficiency (\( \eta_{ARG} \))

\[ \eta_{ARG} = \frac{\left[ 1 - (e_o / e) \right] \left[ 1 - (e_r / o) \right]}{\left[ 1 + (e_o / e) \right] \left[ 1 + (e_r / o) \right]} \]
where,

\[ e = \text{total number of ones in the original machine-part incidence matrix with multiple process plans} \]

\[ o = \text{total number of zeroes in the original machine-part incidence matrix with multiple process plans} \]

\[ e_r = \text{number of voids in the diagonal blocks in the final machine-part incidence matrix} \]

\[ e_o = \text{number of voids in the diagonal blocks in the final machine-part incidence matrix} \]

Several measures have been developed for binary data and a very few measures have been proposed for ordinal level data. It includes Compactness and Sameness measures. Compactness of each cell is defined as the ratio of the number of operations within it to the maximum number of operations possible in it (Nair and Narendran 1997a). To compute the maximum number of operations within a cell, it is assumed that every machine in it processes every component of its corresponding component-family at least once.

\[
\text{Compactness} = \frac{\sum_{k=1}^{c} \text{TOTOP}_k}{c \sum_{k=1}^{c} (\text{TOTOP}_k + \text{NOP}_k)} \quad (2.9)
\]

where,

\[ \text{TOTOP}_k = \text{total number of operations in the } k^{th} \text{ cell} \]

\[ \text{NOP}_k = \text{total number of non-operations (voids) in the } k^{th} \text{ cell} \]

\[ c = \text{Maximum number of machine cells} \]
Nair and Narendran (1997b) have proposed a comprehensive measure, consisting of compactness and separateness that suits to the problems with varying type of input data called Cluster Goodness (CG) which can also be used as a general measure.

\[ CG = qCM + (1-q) SM \]  \hspace{1cm} (2.10)

where,

\[ CM = \text{compactness of all the clusters} \]

\[ CM = \sum_{m=1}^{p} CM_m \]

\[ CM_m = 0, \quad \text{if } n_m = 1 \]

\[ CM_m = \frac{2}{n_m(n_m-1)} \sum_{x_i, x_j \in C_m} s(x_i, x_j) \quad \text{if } n_m < p \]  \hspace{1cm} (2.11)

\[ SM = \text{Separateness of all the clusters} \]

\[ SM = \sum_{m=1}^{p} SM_m \]

\[ SM_m = 0, \quad \text{if } n_m = 1 \]

\[ SM_m = \frac{2}{n_m(n_m-1)} \sum_{x_i \in C_m, x_k \notin C_m} s(x_i, x_k) \quad \text{if } n_m < p \]  \hspace{1cm} (2.12)

where

\[ s(x_i, x_j) = \text{similarity between the } i^{\text{th}} \text{ and } j^{\text{th}} \text{ data unit} \]

\[ n_m = \text{the number of data-units in } m^{\text{th}} \text{ cluster} \]

\[ C_m = \text{the } m^{\text{th}} \text{ cluster} \]

\[ p = \text{number of clusters} \]

\[ I = \text{Total number of data units in all clusters} \]

\[ q = \text{Weightage factor, } 0 \leq q \leq 1 \]
It considers binary as well as ordinal data and can be used as a universal measure for measuring goodness of the solution. The cluster goodness measure considers both compactness of data units within the group and separateness of different clusters. Further, it satisfies the requirements of general measure such as finiteness, ranging between zero and one and influence of singleton clusters.

Aggregate measures are not appropriate shop performance indicators of CM opposed to individual measures of performance of cells/part families (Shafer and Meredith 1993). According to Marsh et al. (1999) practitioners are in favour of disaggregate measures. The users are interested in measures of performance of specific product/part families: lead times, defect rate, costs etc. As these families are always tied to individual cells, this process invariably results in disaggregated measures of cell performance. Managers appeared to be aware that overall shop performance could look worse with the installation of one or more cells; yet, their customer performance and revenue generation might look significantly better. Hence there is a need to concentrate on disaggregate measures of performance.

Ng (1996) has reported that none of the existing measures for the cell formation problem is effective for all classes of problems. However, for well-structured matrices all the existing measures are effective. Hence, selection of measure for cell formation is an important and complex issue.

An analysis of literature on performance measures reveals the following,
• Most of the measures are suitable for zero-one data
• Block diagonalisation is a pre-requisite for the application of existing measures
• For same performance value different configurations can be achieved, i.e., measures are sensitive to the initial disposition of the data.
• Machine utilisation measure does not consider the impact of exceptions in the solution
• No direct performance measure at cell level exists.

Thus, there is a definite need to express the performance of cells in terms of the percentage of the entire product that is being completed within the cell in the context of focused manufacturing. And the same can be used as an objective to form cells.

2.7 STUDIES ON CONCEPTUAL FRAMEWORK FOR CMS CELL FORMATION APPROACHES

The research literature available on GT/CMS is abundant and overwhelming degree focused on the development of procedures to solve the cell formation problem (Wemmerlov and Hyer 1987, Marsh et al. 1999). Several researchers have proposed taxonomy for CMS literature. The summary of selected frameworks is presented in Table 2.1.

Waghodekar and Sahu (1984) have presented a bibliography on GT and other related issues such as production planning and control. Various facets of GT and their impact on implementation and review of solution methodologies for grouping problem have been given by Mosier and Taube (1985).
### Table 2.1 Conceptual framework for cell formation approaches

<table>
<thead>
<tr>
<th>Reference</th>
<th>Classification scheme adopted/framework proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>King and Nakornchai (1982)</td>
<td>Similarity coefficient, Set theoretic methods, Evaluative methods, Other analytical methods</td>
</tr>
<tr>
<td>Wemmerlov and Hyer (1987)</td>
<td>Applicability, Justification, System design and Implementation</td>
</tr>
<tr>
<td>Offodile et al. (1994)</td>
<td>Visual methods; Parts Coding analysis-Mono code, poly code, Hybrid code; Production flow analysis-Matrix formulation (similarity coefficients, Array-based methods), Graph theory, Mathematical formulation(IP, LP, DP) and other structures (system simulation, ES, NN, Fuzzy set theory)</td>
</tr>
<tr>
<td>Reisman et al. (1997)</td>
<td>Theory vs application further divided into Ripple process, Embedding process, Bridging process, Transfer of technology process, Creative application process, Structuring process and Statistical modeling process</td>
</tr>
<tr>
<td>Sarker and Xu (1998)</td>
<td>Mathematical programming methods, Network analysis methods, Material flow analysis and Other heuristic methods</td>
</tr>
<tr>
<td>Selim et al. (1998)</td>
<td>Descriptive approaches, Procedures based on cluster analysis, Graph partitioning approaches, Mathematical programming approaches and Artificial Intelligence.</td>
</tr>
</tbody>
</table>
Offodile et al. (1994) proposed a taxonomic review of literature viz., visual methods, parts coding analysis and production flow analysis. These are further divided into sub-classifications suitably considering the developments in the modeling techniques and solution methodologies. They employ about 65 attributes to describe the model structure, the problem data structure, solution approach, objectives, constraints and decision variables.

Park and Wemmerlov (1995) have proposed a taxonomic framework for CMS problems by considering four major categories viz., asymmetry of model input data, sensitivity to test data, generation of multiple solutions and determination of acceptable solutions. Under input data category the data is further classified into five categories with increase in face value viz., binary data, sequence data, volume data, processing time data and capacity data. A comparative study has been conducted using simple (S), intermediate (I) and complex (C) classification for parts and machines using four different algorithms from the literature by generating data sets using shop structure generator of Park and Wemmerlov (1994). The use of aggregate and disaggregate performance measures has been highlighted. Further, it was concluded that no single technique is best with respect to all measures. Shambu (1996) has proposed a framework for performance evaluation of CMS viz., simulation, analytical and empirical studies.

From these studies the following observations are made

1. With regard to development of analytical models, much work remains to be done in developing models for the design and operation of effective CMS in general.
2. Hypothetical shop data have been employed by the overwhelming majority of the work and not enough effort has been made to justify its appropriateness.

3. The choice of factors and factor levels needs to be more closely linked to the findings of empirical studies.

2.8 STUDIES ON COMPARATIVE EVALUATION OF CMS CELL FORMATION ALGORITHMS

Apart from the contributions in the area of CMS cell design, there are several papers addressing performance evaluation of cell formation algorithms. Some of the comparative studies and their findings are presented below.

Kennedy (1974) has reviewed different clustering methods applied for grouping of employees, grouping of resources using binary data and used distance measure for multivariate analysis. Shafer and Rogers (1991, 1993a, 1993b) have reviewed the developments in the area of similarity coefficients with a special emphasis on measures of association and their effect on cell formation issue raised by Wemmerlov and Hyer (1987). Vakharia and Wemmerlov (1995) have presented a survey of hierarchical clustering techniques and dissimilarity measures. Mosier and Taube (1985), Seifoddini and Wolfe (1986), Chu and Tsai (1990), Gupta (1991), Kandiller (1994) have also compared the performance of known algorithms for cell formation under varying conditions.

Seifoddini (1990) has found that machine-component group analysis methods are suitable when there are no bottleneck machines and similarity coefficient methods, when bottleneck machines exist. Chu and Tsai (1990) have
compared ROC, Direct Clustering Algorithm (DCA) and Bond Energy Algorithm (BEA) and reported that BEA outperformed the other two methods regardless of the measure or data used.

Gupta (1991) has studied the effect of chaining in clustering algorithm and other characteristics of Single Linkage Clustering (SLC), Average Linkage Clustering (ALC), Weighted Linkage Clustering (WLC) and Complete Linkage Clustering (CLC) and reported that CLC is most favourable. Seifoddini and Djassemi (1991) have made a comparative study on the performance of cell formation with Jacard’s similarity and modified Jacard’s similarity with production data such as part volume, route, MH cost.

Miltenburg and Zhang (1991) compared nine well-known algorithms viz., ROC, BEA, MODROC, Ideal seed non-hierarchical clustering algorithm (Chandrasekaran and Rajagopalan 1986a), similarity coefficient algorithm and modified similarity coefficient algorithm of Waghodekar and Sahu (1984). They concluded that there is no algorithm, which consistently finds the best solution. Different algorithms performed better than the rest for different problems. BEA is suggested for small size problems with an alternative to ideal seed algorithm. Shafer and Meredith (1993) have made a comparative study of SLC, ALC, CLA, ROC, DCA and Vakharia and Wemmerlov (1990) method.

Kaparthi and Suresh (1994) have reported certain performance characteristics of a few available cell formation algorithms for large sized problems.

Most of the comparative studies aimed at developing more versatile methods that can identify cells for implementation of CMS. These approaches
help both the research community and the industrial community to understand various issues concerned with each model/approach and its limitations. However, in most of these studies it is concluded that the methods developed are having inherent drawbacks in terms of objectives that can be included, type of data that can be used, size of the problem that can be solved, association measure selection and solution methodology.

2.9 EMPIRICAL STUDIES

Pullen (1976) has reported the results of a survey on 99 cells in 14 companies and the cell size is varying between 6 and 36 machines. Grayson (1978) has reported on the approaches that have been used to evaluate the economic effectiveness of the GT in the context of USSR. Huang and Houch (1985) presented an overview of CMS.

Burbidge (1979) has reported on the implementation status of GT in engineering industry in UK. The study highlighted various issues in detail pertaining to 67 major industries. It is reported that 26 industries have completed the implementation and 10 of them have achieved major benefits. Among several benefits, throughput time reduction is the major achievement. Further, it is reported that 16 industries have failed to implement the concept and quoted mostly due to the lack of a determined individual in the organisation for implementation and the lack of a company wide understanding of the nature of GT and its possible benefits.

Wemmerlov and Hyer (1989) have addressed user experiences and practices through a questionnaire with 200 items covering details of design, implementation and operation of cells. It is reported that about 50% of the
companies surveyed stated that the cells process parts or products for which they had not been originally designed, the new parts fraction ranged between 5 and 25%.

Tatikonda and Wemmerlov (1992) have reported the results from seven case studies on the application of classification and coding systems usage among manufacturers. They also compared the characteristics and experiences of these companies and found that the users are satisfied with their systems and noted that implementation and usage of classification and coding systems are not simple tasks. It is reported that 50% of the firms use coding systems to design cells. It is also stressed the need for research that helps to design cells by means of a suitable database design. Magjuka and Schmenner (1992) have reported on production, plant and administration and human resource considering 463 companies from various parts of the world. The study reported on the above issues from the firms with cells and without cells. It is found that firms with cells are experiencing lower indirect labour, administrative and plant overhead costs. Further the plants with cells able to shift their production process more frequently and quickly from one product to another.

Choi (1996) has conducted a mail survey by sending to 52 plants and reported that 28 responses were usable. This study was concerned with the contingency variables such as conversion scope, financial constraints, product characteristics and their relationship to variables such as cell design techniques, layout configurations and cell independence. It is reported that the organisations are designing cells mostly by using the information on shape/size, routeings, material handling requirements and demand/production volume of parts.
Olorunniwo and Udo (1996) have analysed industrial practices focusing on identification of performance measures and to determine what constitutes successful implementation. This is a mail survey aimed at mapping out of the usage of cell formation techniques in industry and the results were analysed from 57 usable forms. They used delivery response and quality cost as a performance measure. It was found that plants which have many product lines tend to be more successful than those with fewer product lines. Further, it is reported that practitioners form cells by combining parts and products which belong to the same product line.

Wemmerlov and Johnson (1997) have conducted an empirical study in 46 firms containing 126 cells and found that there were many issues unsolved in the area of cell design. Further, it is reported that none of the academic approaches are being used by the industry.

Marsh et al. (1997) have described a field study of 15 metal-machining plants covering 185 cells for cell dynamics. Various issues related to the life of the cells and experiences in redesigning and/or dismantling efforts have been highlighted. It is reported that in about 53% of the cases, layout change has been done to improve material flows or the operators' work situation and does not involve machine replacements. Further it is reported that in 35% of the cases, equipment is exchanged or new equipment added in order to enhance the cells capabilities to process parts, to take advantage of new technology or to meet capacity needs due to increased volumes and in only 6% of the cases the machine configuration modified. In 6% of the cases cells are shutdown completely due to a decision to outsource the production. It is concluded that the cells remarkably resilient to environmental changes.
Marsh et al. (1999) have conducted a field study on the use of 10 popular research presumptions in the industry practices. Out of 14 firms studied, it is reported that hardly 4 presumptions (CM groups dissimilar resources to make part families, Objective to minimise inter cell transfers, larger cells lose efficiency and remainder cells are common) are in agreement and further that these have not been used directly. The average cellularisation reported is around 60% and CMS implementation is incremental in nature. Further it is reported that in 80% of the cases, remainder cell is in use to process parts from other cells and industries are not in favour of subcontracting their parts and/or large scale duplication of resources.

Wemmerlov and Johnson (2000) have studied on various issues related to the implementation of CMS in metal working industry covering 46 plants with totally 126 cells. It is reported that many important issues in CMS cell design remain to be investigated. This survey is very comprehensive in many ways and covered user experiences in the areas such as pre-design issues, organising for cell design, design methodologies, design considerations and constraints, performance evaluation at the design stage, design outcomes and redesign and dismantling of cells from a life cycle perspective.

Wemmerlov and Johnson (2000) have reported that 82% of the cells are formed using part/product routeings, 41% are formed using coding systems developed based on raw materials, customers, end products etc. Where, 11% of the cells are formed purely on informal knowledge. Further, 10 out of 43 cells are formed based on the key components of a product line. While implementation, 79% of the firms form cells one-by-one and the rest have followed a broad master plan for cell conversion based on the principles of focused manufacturing. It is stressed to form cells based on the processes
followed by the industry. The lack of industry use of published cell formation techniques may be attributed to many reasons. The designers of the techniques are required to show how their method fits into the larger process of cell design and how various issues can be handled.

2.10 ANALYSIS OF CMS LITERATURE

About 300 published research articles collected in the area of CMS cell design are analysed based on the following and conclusions are drawn.

Theory vs applied (Reisman et al. 1997)
Type of input data used (Park and Wemmerlov 1995)
Size of problems handled (Selim et al. 1998)
Cost vs non-cost measures (Offlodile et al. 1994 and Chu 1995)

The details of the above classification are given in Table 2.2.

Figure 2.1 shows the trend in the development of theoretical and applied research. It is observed that, in the early stages of GT development, more applied studies have been reported and currently many researchers are concentrating on theoretical studies. From Table 2.2, it is to be noted that 80% are theoretical and 20% are applied studies. The trend in the use of cost and non-cost based measures used by researchers is also given in Figure 2.1. About 25% of the cases are dealt with cost based measures. Many have started using hypothetical cost data. This may be due to the non-availability of cost data. It is also to be noted that many approaches are based on binary data and non-cost based measures.
Table 2.2 Results of classification of literature on cell formation approaches in CMS

<table>
<thead>
<tr>
<th>Period</th>
<th>Total</th>
<th>Theory</th>
<th>Applied</th>
<th>Performance Measures</th>
<th>Data type</th>
<th>Problem Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cost</td>
<td>Non-cost</td>
<td>Binary</td>
</tr>
<tr>
<td>Up to 1970</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1971 - 75</td>
<td>14</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>14</td>
<td>7</td>
</tr>
<tr>
<td>1976 - 80</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>1981 - 85</td>
<td>11</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>1986 - 90</td>
<td>60</td>
<td>52</td>
<td>8</td>
<td>14</td>
<td>46</td>
<td>36</td>
</tr>
<tr>
<td>1991 - 95</td>
<td>99</td>
<td>86</td>
<td>13</td>
<td>22</td>
<td>77</td>
<td>57</td>
</tr>
<tr>
<td>1996 - 99</td>
<td>98</td>
<td>75</td>
<td>23</td>
<td>36</td>
<td>62</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>289</td>
<td>233</td>
<td>56</td>
<td>73</td>
<td>216</td>
<td>156</td>
</tr>
<tr>
<td>% of total</td>
<td>100</td>
<td>80.63</td>
<td>19.37</td>
<td>25.26</td>
<td>74.74</td>
<td>53.98</td>
</tr>
</tbody>
</table>

* - design / part geometry and sequencing information.

Small size problem (m x p) : below 1000
Medium size problem (m x p) : between 1000 and 4000
Large size problem (m x p) : above 4000
Figure 2.1 Trend in the development of theoretical vs applied studies and cost vs non-cost based measures in CMS cell design

Figure 2.2 shows the trend in the application of type of input data viz., binary, interval and other type of data such as ordinal, design, part geometry etc. used in cell formation approaches. From Table 2.2, it is to be noted that many researchers (about 54%) have used binary data followed by interval data (about 30%). The trend in approaches/methods that addressed small, medium and large size problems is shown in Figure 2.3. From Table 2.2, about 60% of the approaches developed can handle small size problems and only about 20% can handle large size problems.
Figure 2.2 Trend in type of input data employed in cell formation studies

Figure 2.3 Trend in problem size handled in cell formation studies
2.11 SUMMARY

Although the majority of the research efforts in the area of cellular manufacturing have been focused on development of methods for cell formation, very little has been discussed in respect of broader organisational context for cell design (Singh 1993, Reisman et al. 1997, Selim et al. 1998, Wemmerlov and Hyer 1987, Marsh et al. 1997,1999, Wemmerlov and Johnson 1997, 2000)

A detailed review of literature revealed that the existing approaches for the design of CMS have limitations for implementing real life large size problems. Researchers in this area are not addressing the real-world problems encountered in the industry (Singh 1993, Reisman et al. 1997, Selim et al. 1998). Instead, they are guided towards problems that can take advantage of their mathematical skills and conventional in nature rather than incremental nature of implementation (Marsh et al. 1999).

In recent years, there has been a considerable shift in the thinking of practitioners with respect to managing manufacturing systems. Customer focused approach to business has resulted in evaluating several choices differently. Of particular interest is the impact of customer focused thinking on cell formation in CMS. The idea of focused factory of Skinner (1974) and that of customer-in organisation of Schonberger (1990) have underscored the need for looking at the cell formation problem in a different fashion.

Another important aspect is the choice of performance measures and parameters included in the study. In real life situations, use of cost based parameters and customer oriented performance measures are preferred over the
non-cost based measures. On the contrary, researchers have often resorted to non-cost measures. In the category of non-cost based measures, there is a wide range of choices available in the literature. Most of the measures are based on several variations of the extent of block diagonalisation (such as inter cell moves, grouping efficiency and efficacy and maximisation of similarity or minimisation of distance measures etc). However, consequent to the shift in the thinking in favour of focused concept, it is possible to make use of more explicit measures. Existing non-cost based measures do not seem to meet this requirement adequately.

A preliminary study of organisations practising CMS concepts in South India revealed that the concept of owning vs sharing of resources has been used to form focused cells. It is understood that these cells are designed using external consultants and internal experts keeping in view the business goals of the organisation. However, this aspect has not been addressed adequately so far in CMS research.

Complete focused CMS resulting in 100% ownership require very high level of dedication of resources, which requires huge investment or outsourcing or design change etc. To overcome this problem, the industries are adopting a strategy of trade-off between owning vs sharing of resources. These shared resources are pooled together into a small job shop like cell, which is nothing but a remainder cell. When part characteristics are not conducive for complete cellularisation, it may result in low value of ownership. Hence, the objective shifts from maximisation of ownership to minimisation of interaction among cells.
A suitable alternative is to design CMS with combination of GT cells and a remainder cell. From the empirical studies Burbidge (1979), Choi (1996), Wemmerlov and Hyer (1989), Marsh et al. (1999) and Wemmerlov and Johnson (2000) it is observed that the extent of cellularisation is around 60% and the rest is done in a job shop environment. It is also observed that 80% of the organisations are in favour of CMS with remainder cell. Further, it is to be noted that in many cases, parts in the cells share equipment with the rest of the plant for further processing. On the other hand, the research contribution in this area is very limited. Further, there is no work reported in the area of FCF using operation sequence data and other more meaningful shopfloor data such as alternate process plans, multiple copies of machines etc.

Based on the above conclusions the following issues are considered in this research.

- A new performance measure called Product Ownership (POW) which would reflect the concept of owning vs sharing of resources that is being practiced in some of the CMS industries, evolved.

- A suitable mathematical model using POW for focused cellular systems is proposed.

- In view of the model complexity for solving large size problems, a methodology based on simulated annealing is developed considering product-component-machine relationship explicitly.
Development of mathematical model for fractional cell formation with the objective of minimisation of inter cell moves, total moves and weighted moves considering relevant constraints.

Development of heuristic approach for fractional cell formation to handle large size real life problems with input data of varying face value viz.,

- Binary data (with well and ill structured matrices)
- Ordinal level data (with multiple copies of machine type)
- Alternate process plans for parts and multiple copies of machine type.