Cellular Manufacturing: Literature Review and Trends

Vikrant Sharma[1], B D Gidwani[2], M L Meena[3*]
[1]Mody University of Science and Technology,Mechanical Engineering Department Lakshmangarh. 332311. India
[2]Asso. Prof., Rajasthan Technical University,Mechanical Engineering Department Kota 324010. India
[3]Asso. Prof., MNIT,Mechanical Engineering Department Jaipur 302017. India
Corresponding author[*]:mlmeenamnit@gmail.com

Abstract

A big challenge for today's batch production industry is to offer fast delivery of a variety of products to the customer. To meet this challenge, manufacturing industries are turning to cellular manufacturing (CM). Cellular manufacturing has engrossed severe research attention in the recent past. CM based on group technology approach where workstations arranged in the form of manufacturing cells and part families are assigned to these cells. Each manufacturing cell performs all or most of the operations required by part families. The primary purpose of CMS is to reduce setup time, cycle time, and improve machining utilization.
This paper intends to perform an investigation of the literature of CM. The paper examines 170 research papers, different definitions of CM, research methodology used and systematic classification. Based on this, the suggestions for possible research issues and development are identified. The investigation results will help academicians, researchers, and experts with an emphasis on the evolution, suitability and research advances in the CM.

Keywords: Cellular manufacturing; Group technology; literature review; Trends.

1. Introduction

Cellular Manufacturing (CM) is an improvement tactic in the production of job shops and batch shops. Group Technology (GT) in CM is used to build part family members according to the same job processing. Machines and parts are then grouped based on in order or immediate techniques. GT is defined as "A manufacturing philosophy in which similar parts are identified and grouped to take advantage of their similarities in design and production." GT is a method in which parts are manufactured by grouping these parts and successively applying similar technological operations for each group. (Mitrofanov, 1966). Cellular manufacturing (CM) is the application of GT, which group machines, dedicated to the part family of similar components (Dekkers, 2018). CM does not just have the adaptability of job shops in creating a wide range of items yet, also, has high production rate and efficient flow (Liu, Wang, & Leung, 2018).
The implementation of a cellular manufacturing system can achieve substantial advantages.
(Sakhaii, Tavakkoli-Moghaddam, Bagheri, & Vatani, 2013).
- Reduced handling of materials
-Reduced tooling and equipment
-Minimized set-up time
-Minimized work-in-process inventory
-Minimized part makespan
-Enhanced operator capability
The main goal of CMS ' design is to categorize family parts, machine cell formation and machine cell allocation for machine cells in order to minimize the movement of parts between cells. (B. Wu, Fan, Yu, & Xi, 2016). GT and CM are suitable for the plant which currently follows batch production and a process type layout. The required condition to apply GT is that the parts can be grouped into part families. Part Family is a collection of components that match form and size. Part families are essential features of GT.
Mitrofanov was the first who introduced the concept of GT philosophy and the machine

grouping problem in the late 1950's. The other early pioneers in the field of GT are Burbidge and Ham. Burbidge in 1960 proposed production flow analysis technique for GT. From 1960-2017 numbers of methods, models and algorithms developed related to various issues in CM.
The aim of this study is to conduct a broad review of CMS literature. This study comprised 170 research papers from more than 15 journals and international conferences. All the more accurately, the purpose of this investigation is to:

- Classify cellular manufacturing research papers according to their approach and methodology
- Explore the trend in cellular manufacturing and identifies future research agenda.

2. Literature review

Numerous articles dealing with the CMS have been published over the last four decades. This study included the work in the area of CMS, published in refereed journals and international conferences. The Table I shows the distribution of research papers in different journals and international conferences. It is shown by bar chart in Figure 1. Figure 2 shows some paper selected year wise.

Journal	*No. of Papers*	*%*
International Journal of Production Research	31	21.6
Computers and Industrial Engineering	21	14.6
Journal of Industrial Engineering	10	6.9
International Journal of Advanced Manufacturing Technology	9	6.3
Journal of Manufacturing System	6	4.2
European Journal of Operation Research	6	4.2
Journal of Intelligent Manufacturing	5	3.3
International Journal of Industrial Engineering Computations	5	3.3
International Journal of Computer Integrated Manufacturing	4	2.6
International Journal of Manufacturing Technology and Management	4	2.6
Applied Mathematical Modelling	3	1.9
International Journal of Production Economics	3	1.9
Advances in Manufacturing	2	1.3
Advances in Production Engineering and Management	2	1.3
Engineering Optimization	2	1.3
Expert Systems With Applications	2	1.3
International Journal of Engineering Science and Technology	2	1.3
International Journal of Flexible Manufacturing Systems	2	1.3
International Journal of Manufacturing Research	2	1.3
International Journal of Service and Operation Management	2	1.3
Journal of Operations Management	2	1.3
Operations Research	2	1.3
Production and Operations Management	2	1.3
Production Engineering	2	1.3

Production Planning and Control	2	1.3
System Engineering	2	1.3
Journal of Chinese Institute of Industrial Engineering	2	1.3
Manufacturing Research and Technology	2	1.3
Other	12	8.2
Total	151	100
International Conferences	19	

Table I. Distribution of research papers

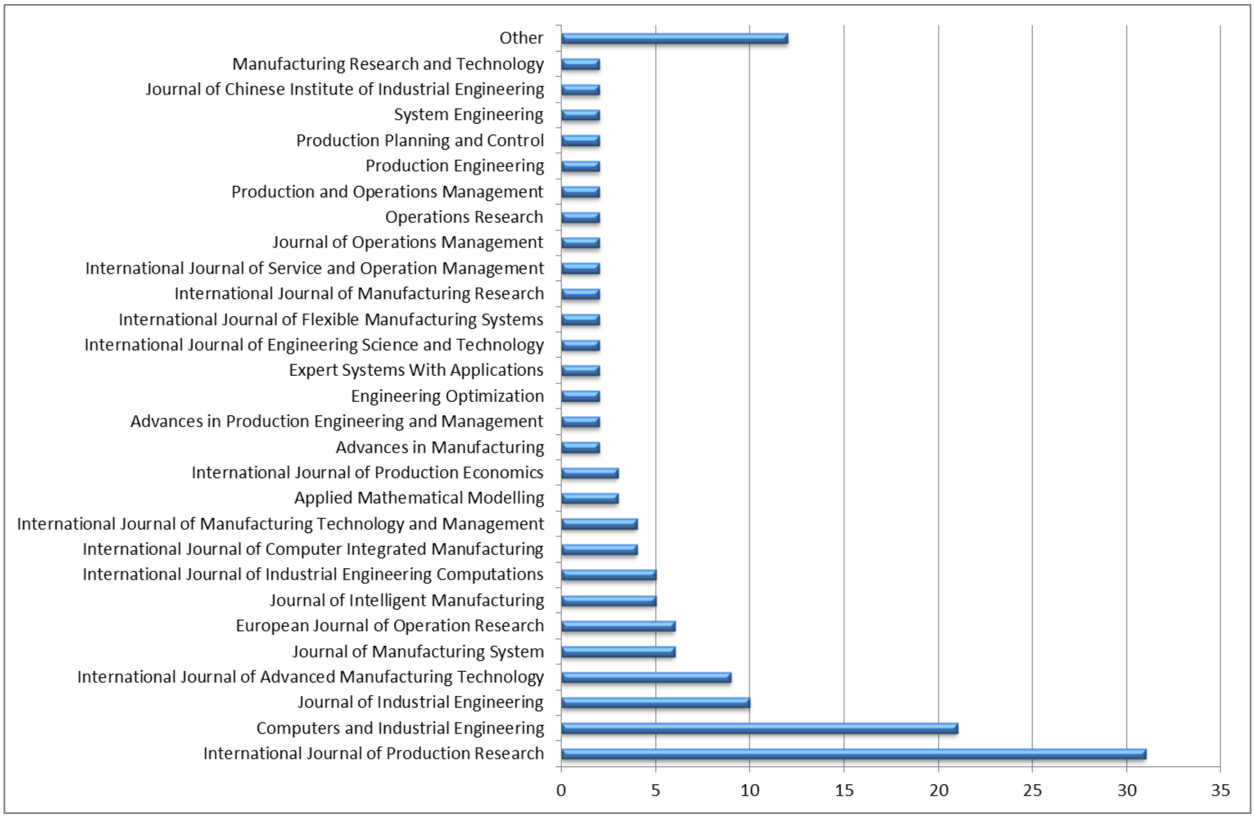

Figure 1. Distribution of Research Papers

Note: Other includes, *Decision Science, Iberoamerican Journal of Industrial Engineering, Information and Control, Innovative Production Machines and Systems, International Journal of Precision Engineering and Manufacturing, Journal of Brazilian Society of Mechanical Science and Engineering, Journal of Information and Optimization Science, Journal of Service Science and Management, Omega, Research Journal of Applied Sciences, Engineering and Technology, Robotics and Computer Integrated Manufacturing, Sadhana Indian Academy of Science.*

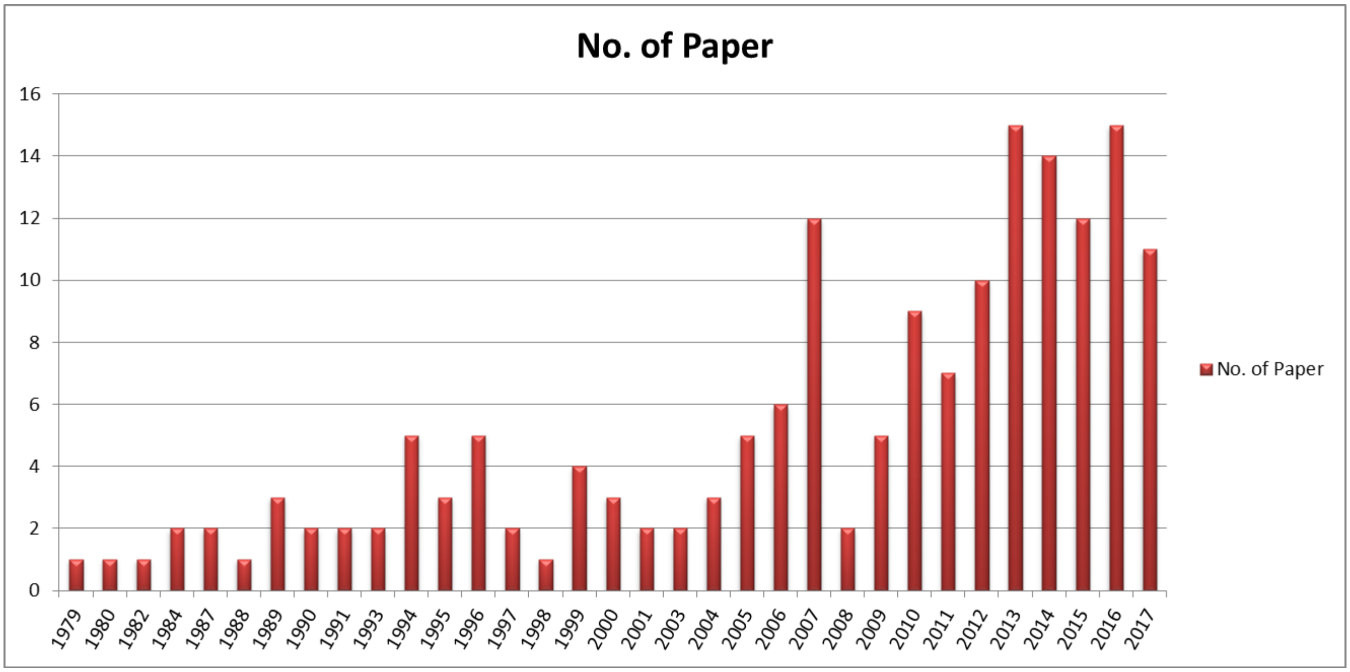

Figure 2. Number of Paper Year Wise

Different meanings of CM given by different researcher are exhibited in Table II.

Table II. Different meanings of CM given by researcher

Author	Connotations of CM
Timothy (1984)	Cellular manufacturing is the physical division of the functional job shop's manufacturing machinery into production cells. Each cell is designed to produce a part family.
Urban (1987)	Cellular manufacturing comprises processing of part families on dedicated groups of different machines (cells).
Heragu (1994)	Cellular manufacturing (CM) can be defined as an application of GT and involves grouping machines or processes on the basis of parts or part families they process
Gursel *et al.* (1995)	Cellular Manufacturing can be defined as the implementation of Group Technology (GT) principles in a manufacturing environment.
Sarker and Mondal (1999)	In cellular manufacturing (CM), parts with similar processing requirements are identified and grouped to form part-families to achieve the benefits of economy
Pillai and Subbarao (2008)	Cellular manufacturing is the practical application of GT in which functionally different machines are grouped to produce a family of parts.
Yousef *et al.* (2011)	In cellular manufacturing (CM), parts requiring a similar production process are grouped in distinct manufacturing cells.
Siva Prasad *et al.* (2014)	Cellular manufacturing systems act as a negotiation between job shop production and flow line production.
Won and Logendran (2014)	CM involves processing a collection of similar parts on a dedicated group of machines.

The research contribution, methodology, and problem -solving approach of all reviewed paper are as shown in Table III.

Table III. Methodology and problem solving approach

Researcher	Year	Methodology	Approach	Contribution to research
Beeby	1979	Conceptual	Type A[1]	Presented a broader view of GT
Witte	1980	Descriptive	Type A[1]	Introduced a method for designing cell based on similarity coefficient
Vaithianathan and McRoberts	1982	Descriptive	Type B[2]	Examines a group technology from a scheduling point of view and presented a modified approach to scheduling in GT
Waghodekar and Sahu	1984	Descriptive/Applied	Type A[1]	Discusses the problem of machine-component cell creation in GT and presents a heuristic approach founded on the similarity coefficient.
Greene and Sadowski	1984	Conceptual	Type A[1]	Discusses the capabilities and merits of a group technology cellular manufacturing system.
Chandrasekharan and Rajagopalan	1987	Applied	Type A[1]	Develop an algorithm for simultaneous formation of part-families and machine-cells in GT.
Wemmerlov and Hyer	1987	Empirical	Type C	Recognizes a substantial number of research points for cellular manufacturing and discusses the requirement for their investigation and proposes proper methods for their study.
Shaw	1988	Descriptive	Type B[2]	Describes artificial intelligence based approach for dynamic scheduling method for cellular manufacturing systems.
EIMaraghy and Gu	1989	Applied	Type B[1]	Presented a technique for the direct and automatic assignment of parts to flexible manufacturing cell.
Chu	1988	Empirical	Type C	Focuses on a state-of-the-art review on the use of clustering techniques in cellular manufacturing.
Gunasingh and Lashkari	1989	Applied	Type A[1]	Proposed a 0-1 integer programming formulations to group the machines in CMS based on tooling desires of the parts, tooling accessible on the machines and the preparing times.
Harhalakis *et al.*	1990	Applied	Type A[2]	Presented a simple twofold heuristic algorithm for cell manufacturing capable of minimizing inter-cell material movement.
Vohra *et al.*	1990	Applied	Type A[2]	Presents a non-heuristic network method for cell formation with less intercellular interactions.
Sule	1991	Descriptive	Type A[1]	Develops a process in GT to decide groupings of machines, the aggregate number of machines required and the aggregate of material exchange between the cells so parts can be prepared with least aggregate cost.
Gupta	1991	Comparative	Type A[1]	Exhibited results from an examination performed to discover the seriousness of chaining problem and other features related to different linkage clustering algorithms.

Siier and Saiz	1993	Conceptual	Type B[1]	Confers the control of manufacturing cells and emphases on cell loading aspects.
Wu and Salvendy	1993	Applied	Type A[1]	Presented a basic network model for the cell formation given operation sequences.
Alford	1994	Empirical	Type C	Explore the current state and history of the ideas behind cellular manufacturing and its application in industry.
Srinivasan	1994	Applied	Type A[1]	Introduce a grouping algorithm for machine-cell formation using a minimum spanning tree.
Seifoddini and Hsu	1994	Comparative	Type A[1]	Present a new execution measure and conducted a reasonable investigation of three distinctive similarity coefficients approach.
Logendran *et al.*	1994	Applied	Type A[1]	Presents a realistic approach to the problem of selecting machines and a unique process plan for each part of a cellular manufacturing system.
Heragu	1994	Empirical	Type C	Provides a through a survey of papers on GT and CMS design.
Siier *et al.*	1995	Descriptive	Type B[1]	Depicts manufacturing cell loading principles and algorithms for associated cells.
Srivastava and Chen	1995	Applied	Type A[1]	Endorse a quadratic programming model for machine cell creation with congestion constraint, which also finds the optimal number of machine cells.
Malmborg	1995	Applied	Type A[1]	Develop a buffer storage resource allocation model for cellular manufacturing system.
Sridhar and Rajendran	1996	Applied	Type B[2]	Presented a genetic algorithm for scheduling and flow line based CMS is considered with the objectives of minimizing makespan, total flow time and machine idle time.
Batocchio and Irani	1996	Descriptive	Type A[1]	Addressed the feasibility of rapid computer implementation of production flow analysis.
Drolet *et al.*	1996	Empirical	Type A[1]	Focuses on exposing fundamental roots of dynamics cellular manufacturing and virtual cellular manufacturing.
Shambu	1996	Empirical	Type A[1]	Presented a performance evaluation of cellular manufacturing systems.
Rheault *et al.*	1996	Conceptual	Type A[1]	Gives a dynamic cellular manufacturing system (DCMS) that withstands the intense situation of small make-to-order producers and subcontractors.
Reisman *et al.*	1997	Empirical	Type C	Focuses on entire life cycle literature of cellular manufacturing as a module of OR/MS addresses the research strategy employed and exhibited by the authors.
Seifoddini and Djassemi	1997	Descriptive	Type A[1]	Introduced a method for the affectability investigation of the execution of a CMS considering changes in product mix.

Selim *et al.*	1998	Empirical	Type C	Confers and reviews an critical issue in CM focusing on cell formation.
Sarker and Mondal	1999	Empirical	Type C	Presents a brief comparative study of some existing grouping efficiency measures in CM.
Suer *et al.*	1999	Descriptive	Type B[1]	Mentioned growing importance of cellular manufacturing and introduce new rules for cell loading considering a multi-cell environment.
Ernzer and Kesavadas	1999	Conceptual	Type A[1]	Discusses numerous cell formation and visualization methods developed particularly for the outline of the virtual industrial facility.
Lozano *et al.*	1999	Applied	Type A[1]	Presents a tabu search algorithm that deliberately investigates possible configurations of the machine cell that determines the corresponding part families using a linear network flow model.
Islam and Sarker	2000	Applied	Type A[1]	Developed a mathematical model using similarity coefficient for optimally solving the cell formation problem in CM.
Sarker and Xu	2000	Applied	Type A[1] Type A[3]	Developed a 3-step operation sequence and cost-based method that incorporates the cell formation and the layout of intracell to lessen the aggregate cost of the machine investment and materials flow.
Davis and Mabert	2000	Applied	Type B[1]	Developed and assessed mathematical programming-based procedures that exploit the structure of both independent and linked CM settings for making labour assignment and order dispatching decisions before the start of the shift.
Onwubolu and Mutingi	2001	Applied	Type A[1]	Demonstrated the issue of cell formation with three objective functions: a) minimization of intercellular movements, b) minimization of cell load variation, and c) mix of these options.
Low *et al.*	2001	Descriptive	Type A[1]	Concentrated on seven cell formation techniques used in cellular manufacturing. The performance of each method was measured using grouping measures.
Agarwal *et al.*	2003	Applied	Type A[1]	Proposed an Analytic Hierarchy Process (AHP) based framework for the assessment of the cell formation methods.
Wang	2003	Applied	Type A[1]	Proposed a linear assignment algorithm for machine-cell and part-family formation for the design of CMS.
Solimanpur *et al.*	2004	Applied	Type B[2]	Talks about the scheduling of manufacturing cells in which parts may need to visit different cells and proposed a two-step heuristic to solve the problem.
Malakooti *et al.*	2004	Applied	Type A[1]	Developed an integrated approach to solve cell formation based on process planning and production planning simultaneously.

Johnson and Wemmerlov	2004	Empirical	Type A^1	Reconnoitre why cell implementation breaks in companies that already have cells.
Sakazume	2005	Comparative	Type C	Compared the similarities and differences between Japanese Cell Manufacturing and Cellular Manufacturing.
Prabhaharan *et al.*	2005	Applied	Type A^2	Suggested an ant colony system approach for cell formation with the goal of decreasing the aggregate cell load difference and the total intercellular transfers.
Durmusoglu and Nomak	2005	Descriptive	Type A^1	Described GT cells design and its execution in a glass mould manufacturing industry.
Franca *et al.*	2005	Applied	Type B^2	Suggested Genetic Algorithm and a Memetic Algorithm for the scheduling of part families in a flow shop manufacturing cell.
Moghaddam *et al.*	2005	Applied	Type B^1	Built up a mathematical model with the objective function of minimalizing the idle time of machine in cells and delivery time to the clients.
Dimopoulos	2006	Applied	Type A^1	Present's multi-objective GP-SLCA, an evolutionary computation approach for the multi-objective cell-formation problem.
Murugan and Selladurai	2006	Applied	Type A^1	Studies three array-based clustering algorithms for cell formation, with a real case study to exhibit the viability of algorithms.
Hachicha *et al.*	2006	Applied	Type A^1	Apply correlation analysis (CA) for solving cell creation problem
Nsakanda *et al.*	2006	Applied	Type A^1	Present a comprehensive model for designing CMS for multiple process plan and routing using a genetic algorithm
Bansee and Chowdary	2007	Conceptual	Type A^1	Considers the new concept of virtual cellular manufacturing (VCM) to improve the effectiveness of manufacturing operations by varying the methods of production.
Dimopoulos	2007	Applied	Type A^1	Described a new methodology based on multi-objective GP-SLCA, for the multi-objective cell-formation problem.
Pham *et al.*	2007	Applied	Type A^1	Proposed Bees Algorithm based optimization technique for solving cell formation problem.
Das *et al.*	2007	Applied	Type A^1	Revealed a multi-objective mixed integer programming model for CMS design that diminishes aggregate cost and enhances the machine reliabilities in a cell.
Wang *et al.*	2007	Applied	Type A^1	Presents a new clique partitioning (CP) model for the group technology problem.
Balakrishnan and Cheng	2007	Empirical	Type C	Review research to addresses CM under states of multi-period planning horizons,

				with demand and resource suspicions.
Mak *et al.*	2007	Applied	Type A^1	Presents ant colony optimization based algorithm for production scheduling and manufacturing cell formation.
Kulkarni and Shanker	2007	Applied	Type A^2	Presents a mathematical model using GA for layout problem in cellular manufacturing.
Venkataramanaiah	2007	Applied	Type B^2	Developed a simulated annealing based algorithm for scheduling of parts with the goal of minimizing idle time, flow time and makespan.
Hachicha *et al.*	2007	Applied	Type A^1	Apply multivariate approach based on a correlation analysis for cell formation problem.
Wu *et al.*	2007	Applied	Type A^1	Developed a hierarchical GA for forming machine cells and for determining the group layout of a CMS.
Wu *et al.*	2007	Applied	Type A^1 Type A^2 Type B^2	Proposed a conceptual framework and developed a hierarchical genetic algorithm that integrates cell formation, cell layout, and group scheduling.
Mahdavi and Mahadevan	2008	Applied	Type A^1 Type A^2	Talks about the joint problem of the cell formation and the cellular layout using the CLASS algorithm.
Pillai and Subbarao	2008	Descriptive	Type A^1	Established a robust design methodology for designing CMS that involve dynamic and deterministic production requirement.
Sangwan and Kodali	2009	Applied	Type B^1	Proposed a multicriteria Quadratic Assignment Problem for CMS layout with the objective of increasing the closeness rating and reducing the material handling cost
Ahi *et al.*	2009	Applied	Type A^1 Type A^2	Suggested a two-step method for cell formation, cell layout, and intracellular machine layout as three necessary steps in the design of CMS by applying multiple attribute decision making concepts.
Ahkioon *et al.*	2009	Descriptive	Type A^1 Type B^1	Examines the problem of designing CMS for various factors like operation sequence, multi-period production planning, machine capacity, dynamic system reconfiguration, and machine procurement.
Kioon *et al.*	2009	Applied	Type A^1 Type A^2	Projected a model for CMS design considering production planning and system reconfiguration decisions and solved it using integer non-linear program
Aliabadi *et al.*	2010	Applied	Type A^1	Presented a mathematical approach for modelling the CM system design problem for assembly aspects.
Abadi *et al.*	2010	Applied	Type A^2	Proposed a model for the design and layout of CMS for dynamics demand.
Papaioannou and Wilson	2010	Empirical	Type C	Presents cell formation literature survey with the focus on different cell formulation

				methods proposed by researchers during 1997-2008.
Ribeiro	2010	Applied	Type A[1]	Presented a method of colouring graphs for cell formation in CM.
Aryanezhad *et al.*	2010	Applied	Type A[1] Type B[2]	Proposed a mathematical model for cellular manufacturing system design problem considering scheduling and cell formation issues concurrently.
Kesen *et al.*	2010	Applied	Type B[2]	Proposed a GA based heuristic approach for job scheduling in the design of CM cells.
Ghosh *et al.*	2010	Empirical	Type A[1]	Discusses various metaheuristic techniques of cell formation problem in cellular manufacturing
Sarac and Ozcelik	2010	Applied	Type A[1]	Proposed GA for cell formation in a cellular manufacturing system.
Elmi *et al.*	2011	Applied	Type B[2]	Suggested an integer linear programming model for the scheduling issues to reduce the makespan considering movement between inter-cell and non-consecutive multiple processing of parts on a machine in CMS.
Garbie	2011	Empirical	Type A[1]	Offered a concept for transforming job shop manufacturing systems into cellular manufacturing system (CMS) considering globalization issues.
Modak *et al.*	2011	Comparative	Type A[1]	Employed SLCA, C-Linkage, and K-Means algorithms to form part families.
Akturk	2011	Applied	Type B[1]	Developed a hierarchical multi-objective heuristic algorithm for the cell loading decisions, lot sizes for every item and sequencing of items containing the GT families at each manufacturing cell with the objective function of reducing the setup, inventory holding, overtime and tardiness costs.
Taghavi-fard *et al.*	2011	Applied	Type B[2]	Presents a position-based learning model in CMS for group scheduling in flow shop systems with the objective to minimize makespan and total tardiness.
Arora *et al.*	2011	Empirical	Type C	Confer different techniques of cell formation and show the significant research work done in the past years to bring up the research gap.
Kanani *et al.*	2011	Applied	Type B[2]	Presents a new mathematical model for a multi-criteria GT problem in CMS to reduce the makespan and costs of intercellular movement, tardiness, and sequence-dependent setup, simultaneously.
Kruger	2012	Empirical	Type C	Presented a case study on employing CM in a make to order manufacturing system.
Zee	2012	Descriptive	Type B[1]	Presented family-based dispatching with batch availability
Egilmez and Siier	2012	Empirical	Type B[1]	Works on a cell loading problem for a

				multi-period as a case study in an organization with the objective of minimizing the total tardy jobs.
Arkat *et al.*	2012	Applied	Type A[1]	Developed branch and bound algorithms for the cell formation problem in CMS.
Arkat *et al.*	2012	Applied	Type A[1] Type A[2]	Presents a mathematical model for simultaneously identifying the cell formation, cellular layout and the operation's sequence of jobs in a cell with the objective to minimize makespan as well as total transportation cost of parts.
Karthiikeyan *et al.*	2012	Descriptive	Type B[2]	Tended to the issue of scheduling in cellular manufacturing systems that comprises of various manufacturing cells with the aim to minimize the penalty cost.
Mutingi *et al.*	2012	Applied	Type A[1] Type A[2]	Presents an improved algorithm for discourse cell formation and cell layout problems simultaneously considering the sequence of data.
Aghajani *et al.*	2012	Applied	Type A[1]	Introduce a mixed-integer nonlinear programming model to lessen the cost of determining the number of kanbans, size of the batch, and the total number of batches in CMS.
Pasupuleti	2012	Applied	Type A[1]	Proposed a methodology for arranging the parts, as well as scheduling in a cellular manufacturing system.
Zadeh *et al.*	2013	Descriptive	Type A[1]	Presented a broad framework of integrated production planning, process planning and control in CM and also developed an integrated model based on Integrated Modelling Language.
Dixit and Gupta	2013	Empirical	Type C	Presents the results of a survey carried out in implementing cellular manufacturing system in Indian industries
Arora *et al.*	2013	Empirical	Type C	Confer different techniques of cell formation and show the major research work done in the past years to bring up the research gap.
Javadi *et al.*	2013	Applied	Type A[2] Type A[3]	Presented a novel mathematical model for the inter-cell and intra-cell layout problem in designing CMS under the dynamic environment.
Chang *et al.*	2013	Applied	Type A[1] Type A[2]	Formulated a two-stage mathematical programming model to incorporate cell formation, cell layout and intracellular machine sequencing issues considering alternative process routings, operation sequences, production volume, and the cellular layout type.
Alhourani	2013	Applied	Type B[1]	Developed a novel broad similarity coefficient that includes multiple process routings, the sequence of operations, production quantity, duplicate machines,

				and machines capacity in CM.
Metternich	2013	Descriptive	Type A[1]	Focuses on finding appropriate performance indicators to assess economic fields of application of CM with a practical example of milling.
Solimanpur and Elmi	2013	Applied	Type B[2]	Offered a mixed-integer linear programming model for scheduling issues in CM.
Megala and Rajendran	2013	Applied	Type A[1]	Proposed an improved ant-colony optimization (IACO) algorithm for cell formation.
Askin	2013	Empirical	Type A[1] Type C	Reviews the increases in CM area of particular importance on the IJPR and presented general formulation for the design of CM.
Kia *et al.*	2013	Applied	Type A[2]	Proposed a multi-objective mixed-integer nonlinear programming model for CMS layout design.
Carmo-Silva	2013	Empirical	Type C	Carried out a complete industrial study for changing a production system into CMS in a leather manufacturing company.
Das *et al.*	2013	Empirical	Type A[1]	Provides an overview of the important features of group technology.
Ayough *et al.*	2014	Applied	Type B[2]	Presented a new mathematical model for job shop scheduling problem in virtual manufacturing cells that minimizes the completion time of all jobs.
Baykasoglu and Gorkemli	2014	Applied	Type A[1]	Presented a new agent-based clustering algorithm for cell formation in CM by considering the dynamic environment.
Shiyas and Pillai	2014	Applied	Type A[1]	Presents an algorithm for part families and manufacturing cells design with the objective to maximize grouping efficiency.
Li *et al.*	2014	Applied	Type A[1]	Developed a combinational ant colony optimization (CACO) approach, for the single-processing machines and the batch-processing machine, respectively.
Arkat and Ghahve	2014	Applied	Type B[2]	Proposed a bi-objective mixed integer programming model for scheduling in virtual manufacturing (VM) cells with outsourcing.
Neufeld *et al.*	2014	Descriptive	Type B[2]	Emphases on the flow shop group scheduling problem with the objective to minimize makespan.
Halat and Bashirzadeh	2014	Applied	Type A[2]	Developed an integer linear programming model, considering intercellular movement times, exceptional elements and sequence-dependent family setup times.
Khanna *et al.*	2014	Empirical	Type C	Presents a succinct review of the literature in group technology.
Raja and Anbumalar	2014	Applied	Type A[1] Type A[3]	Presents a new heuristic approach considering the flow matrix which simultaneously finds part grouping and cell formation, intracellular layout, and voids

				issues for the design of CMS.
Darla *et al.*	2014	Applied	Type A[2]	Developed a mathematical model considering intercellular movement and cell load variation and optimize the solution using GA.
Seifermann *et al.*	2014	Empirical	Type A[1]	Presents an evaluation of work measurement concepts for cellular manufacturing.
Won and Logendran *et al.*	2014	Applied	Type A[1]	Proposed an effective two-phase p-median approach for the cell formation (CF) in the CMS design.
Costa *et al.*	2015	Applied	Type B[2]	Developed a hybrid genetic algorithm (GA) incorporating features from random sampling to minimize the makespan in a flow shop scheduling problem.
Ulutas	2015	Applied	Type A[1]	Introduce a Clonal Selection Algorithm to solve cell formation problem and generate optimal cell assignment based on machine/part matrix.
Pimentel and Martins	2015	Empirical	Type C	Implemented cellular manufacturing concept in Durit company with the objective of minimizing non-value added operations.
Zeng *et al.*	2015	Applied	Type B[1]	Presented a nonlinear mathematical programming model to find out the sequences of the parts processed on the machine.
Alhourani	2015	Applied	Type B[1]	Developed a novel similarity coefficient which integrates machine capacity, machine reliability and parts alternative process routing.
Egilmez and Suer	2015	Descriptive	Type B[1]	Addresses a multi-period cell loading problem with objectives to reduce the number of tardy jobs and optimize the scheduling of tardy job.
Haraguchi *et al.*	2015	Descriptive	Type B[2]	Proposed operator allocation and scheduling method using skill index for practical training under the stable order condition.
Liu *et al.*	2015	Applied	Type A[1]	Introduced a new optimization model for CMS under dual-resource constrained setting along with an efficient discrete bacteria foraging algorithm (DBFA)
Karim and Biswas	2015	Empirical	Type A[1]	Address the major works within the field of cell formation problem in a batch-oriented production system with a focus on models and algorithms established for obtaining the solution for the primary issue of the design of cell manufacturing.
Kumar and Sharma	2015	Applied	Type A[1]	Develop an easy and simple to understand cell formation technique by considering the number of production and manufacturing flexibility-related factors.
Ghosh *et al.*	2015	Applied	Type A[2]	Suggested a new Immune Genetic

				algorithm (Immune- GA-RS) for inter-cell layout in the CMS.
Li *et al.*	2015	Applied	Type B[2]	Presents a hybrid harmony search for flow line manufacturing cell scheduling problem (FMCSP) with the objective of minimizing total tardiness and mean total flow time.
Delgoshaei *et al.*	2016	Empirical	Type C	Presents a review of material moving techniques with their effects on CMS.
Houshyar *et al.*	2016	Applied	Type A[1]	Proposed the linear mathematical model for dynamic CMS for grouping the machines in the cell.
Kamalakannan *et al.*	2016	Applied	Type A[1]	Proposed an ant colony algorithm to solve the cell formation problem based on machine-index and part assignment rule with the objective of increasing group efficacy.
Karthikeyan *et al.*	2016	Applied	Type A[1]	Proposed a meta-heuristics for the design of Dynamic Cellular Manufacturing System (DCMS) using a genetic algorithm to minimize holding cost, back order cost, machine cost, and salary cost.
Imran *et al.*	2016	Applied	Type A[2]	Proposed a simulation integrated hybrid GA for layout design in CMS to minimize the cost of value-added work in processes.
Hazarika and Laha	2016	Applied	Type A[1]	Proposed a heuristic approach based on Euclidean Distance matrix for cell formation in multiple routes, process sequential and parts volume problems.
Mohammadi and Forghani	2016	Applied	Type A[2]	Present a S –shaped new layout framework, for the design of the layout of CMS.
Amruthnath and Gupta	2016	Applied	Type A[1]	Presented a modified rank order clustering (MROC) method for cell formation considering weight and data reorganization.
Raja and Anbumalar	2016	Applied	Type A[1]	Proposed a newly generalized similarity coefficient method to integrate feasibility assessment and cell formation problem with the consideration of operation sequence
Saad	2016	Descriptive	Type A[1]	Investigated the effects features associated with demand variation like the arrival of material and the product mix in CMS.
Fahmy	2016	Applied	Type A[1] Type A[2] Type B[2]	Presented a GA to solve cell formation, GT layout, and scheduling problem concurrently.
Suemitsu	2016	Applied	Type A[2]	Proposed a new multi-objective layout design optimization technique for robotic cellular manufacturing system layouts that can simultaneously determine the task scheduling and positions of manufacturing components.
Yang *et al.*	2016	Applied	Type A[1]	Proposed an improved discrete particle swarm optimization method to reduce the

				makespan.
Bychkov and Batsyan	2017	Applied	Type A[1]	Proposed a novel mixed-integer linear programming model for solving the problem of cell formation with a variable number of manufacturing cells.
Bychkov *et al.*	2017	Applied	Type A[1]	Presents a new heuristic algorithm for solving the cell formulation problem.
Romero - Dessens	2017	Empirical	Type A[1]	Designed an efficient value stream mapping to improve the flow of materials and increase the productivity by eliminating non-value added activities at an electronic components manufacturer
Allahyari and Azab	2017	Applied	Type A[2] Type A[3]	Formulated a bi-level mixed-integer non-linear programming model to discuss the problem and to identify the relationship between intra-cell and inter-cell layout design.
Delgoshaei and Ali	2017	Applied	Type B[1]	Proposed a method for location-allocation of skilled workers in CMS and solved the model using ant colony optimization
Feng *et al.*	2017	Applied	Type A[1] Type B[1]	Introduce a linear model for allocation of machine, parts, and the worker using particle swarm optimization
Tariq and Bulgak	2017	Applied	Type A[1]	Presented a mixed integer linear programming model for production planning and the cell formation problem
Yiyo and Liu	2017	Applied	Type B[1]	Proposed a mixed-integer programming model for worker assignment considering inter-cell workforce transfer.
Jawahar, and Subhaa	2017	Applied	Type A[1] Type B[1] Type B[2]	Proposed a linear model for part machine assignment to the cell, number of cell and scheduling. Author solved the model using GA.
Rezazadeh *et al.*	2017	Applied	Type A[1]	Presents a mathematical model to improved product quality and reliability of CMS. Author solved the model using GA.
Almonacid *et al.*	2017	Applied	Type A[1]	Employ the firefly algorithm and Egyptian vulture optimization algorithm for the cell for cell design problem.

Different research studies are divided into four types – conceptual, descriptive, empirical and comparative. (Dangayach and Deshmukh, 2001). The connotation of these research methodologies is given below:

- *Conceptual:* basic or fundamental concepts of CM
- *Descriptive:* explanation or description of CM content or process, performance measurement issues.
- *Empirical:* data for the study has been taken from existing database, review, case study, taxonomy, or typological approaches.
- *Comparative:* comparison between two or more practices or solutions and the evaluation of the best method or a solution.

Apart from these, many researchers also used applied type research methodology refers to scientific study and research that seek to solve practical problems in cellular manufacturing.
The different problem-solving approaches used by different researchers are cassified into six types- Type A^1, type A^2, Type A^3, Type B^1, Type B^2 and Type C. The meaning of these approaches is given below:

Type A^1: Conceptual and cell formation related approach
Type A^2: Arrangement of the cells within the shop floor (inter-cell) related approach
Type A^3: Arrangement of the machine within each cell (intra-cell) related approach
Type B^1: Cell loading and assignment pertaining approach
Type B^2: Cell scheduling pertaining approach
Type C: Review and case study related approach

3. Descriptive analysis of the research papers

Some of the discussion and explanations on the literature review from Table III are offered in this section.
Dispersion of different research methodologies utilized by multiple researchers appears in Table IV and Figure 3. A result shown in Table IV represents that around 63 percent of papers are applied based research in CM. This is a healthy sign that most of the researchers are focusing on the design of CM. Table IV also reveals that comparative studies are less detailed when contrasted with other methodologies and only 1 percent studies based on a blend of different research methodologies.

Table IV. Percentage distribution of different methodology

Methodology	Percentage
Applied	63 %
Empirical	17 %
Descriptive	12 %
Conceptual	4 %
Comparative	3 %
Mixed	1 %

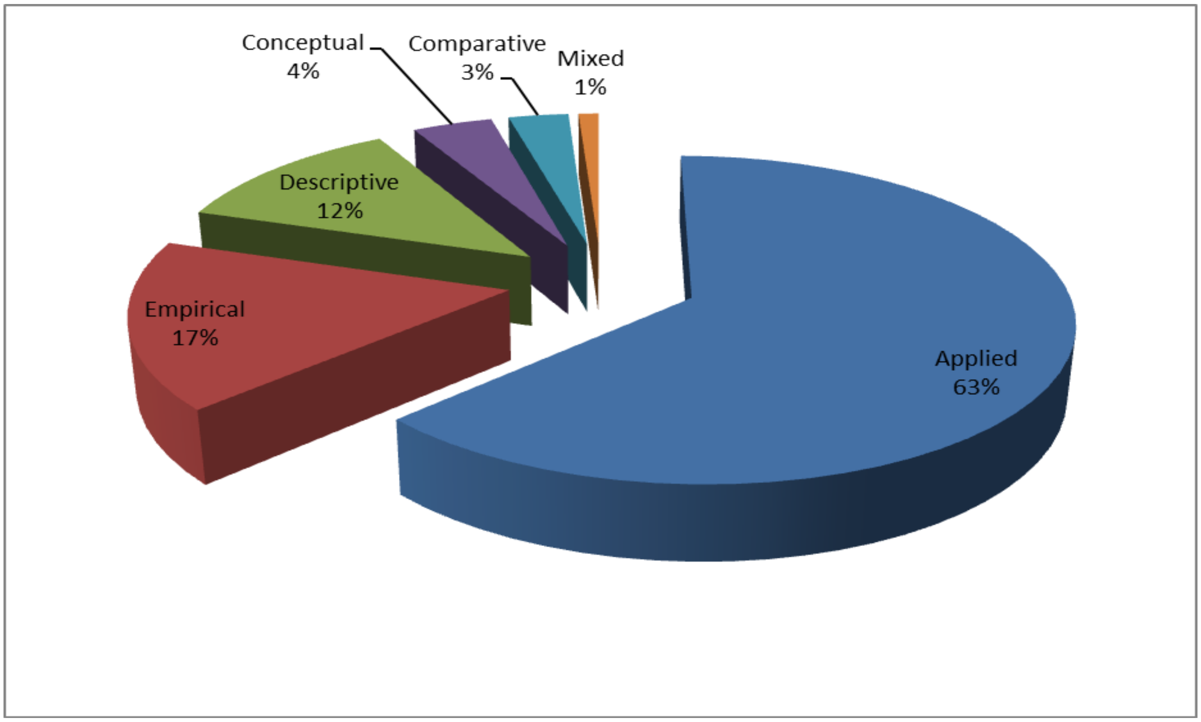

Figure 3. Distribution of Methodology Used In CM Literature

Distribution of various problems solving approach related to CM utilized by researchers appears is shown in Table V and Figure 4. The result shown in Table V shows that 51 percent of papers are Type A^1 problem-solving approach that is discussing cell formation related issues in CM. It is evident from this data that the cell formation aspects appear to lead research theme throughout the literature and layout and scheduling related issues seem to have gotten less consideration from researchers. Furthermore, there is less attention to combination type approach.

Table V. Percentage distribution of different problem solving approach

Problem-solving approach	Percentage
Type A^1	51 %
Type B^2	11 %
Type C	10 %
Type B^1	10 %
Mixed	10 %
Type A^2	8 %
Type A^3	0 %

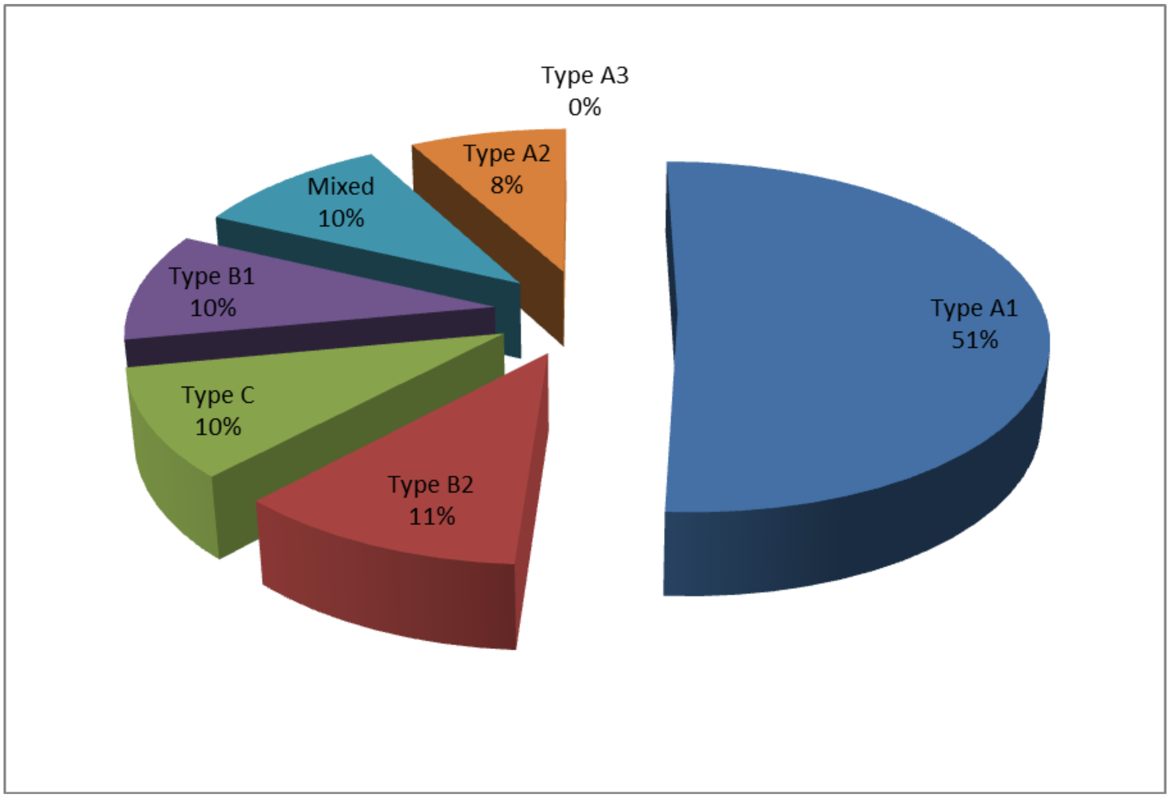

Figure 4. Distribution of Various Problems Solving Approach Related To CM

The trend of authorship countrywide is as follows. United States of America (USA) drove the research with more than 22 % of total articles followed by India with more than 19 % of full articles. Iran came third by producing 13 % of the research articles. Contributions of other countries are China 6 %, Canada 4 %, and Turkey 4 %. Contributions of the countries with less than 3 % are Germany, Hong Kong, Italy, Japan, UK, South Africa, Malaysia, Mexico, Netherlands, Singapore, Oman, Korea and West Indies.

As cell formation aspects have a dominant research theme in the literature, the following section discusses various cell formation techniques in brief.

4. Cell formation technique

Early techniques developed for solving group technology, and cellular manufacturing problems are as follows:

Visual inspection is the technique where parts are classified into part families, based on the components or pictures of the parts. However, this technique is unsuitable for large-scale and though this approach is easy to understand its success is depended on human experience.

Classification and coding are an improvement on the previous technique where parts are classified into appropriate families, based on the number of attributes, such as dimensions of the part; a shape of the part; material of part; tolerance requirement. Usually, each part is assigned a code and each code representing an attribute of the part. Parts with the same codes are formed into the same part family. It may be because of the design orientation and exclusive nature of most coding techniques; they are not famously known as the research literature of CM. Like other, this technique also tries to group parts into families assuming likenesses in design and manufacturing attributes. This idea was first presented by Mitrofanov [1966] and Opitz et al. [1969].

Production flow analysis (PFA) is the technique where parts are classified into appropriate families using routing information or operation sequences. This technique also identifies machine cells using input as a complete list of machines and machine capabilities.

In last few decades' numbers of researchers have developed methods for formation of cells in cellular manufacturing as shown in Table VI.

Table VI. Different cell formation methods

Cell Formation Methods			
Mathematical Programming	**Cluster Algorithm**	**Heuristics and Meta-heuristics**	**Artificial Intelligence**
Assignment	Bond Energy Analysis	Ant Colony Optimization	Fuzzy Approach
Integer Programming	Rank Order Clustering	Bees Algorithm	Neural Network
Linear Programming	Modified Rank Order Clustering	Discrete Bacteria Algorithm	
Mixed Integer Linear Programming	Similarity Coefficient	Egyptian Vulture Optimization Algorithm	
Quadratic Programming		Genetic Algorithm	
		Particle Swarm Optimization	
		Simulated Annealing	
		Tabu search	

Mathematical programming methods are commonly in use in cellular manufacturing systems. A researcher proposes mathematical methods of programming such as linear programming, goal programming and dynamic programming. Mathematical programming methods can easily include some design logic in their objective functions and constraint functions. One of the first to apply linear programming in the GT program was Purcheck (1975). In the case of part families and machine grouping, Srinivasan proposed an assignment model. These techniques solve the machine-part grouping problem optimally. Being an optimization method, the objective of this method could be to maximize the total sum of likenesses between each pair of machines or parts. The researchers, who utilized distinctive mathematical programming techniques to formulate the cell formation problem, are presented in Table VII.

Table VII. Mathematical techniques and researchers

Mathematical Technique	Researchers
Assignment	(Srinlvasan, Narendran, & Mahadevan, 1990) (J. Wang, 2003) (Sangwan & Kodali, 2009)
Integer Programming	(Gunasingh & Lashkari, 1986) (Balakrishnan & Cheng, 2007) (Ah kioon, Bulgak, & Bektas, 2009) (Egilmez & Suer, 2012) (Javani, n.d.)
Linear Programming	(Davis & Mabert, 2000) (Malakooti, Malakooti, & Yang, 2007) (Aliabadi & Aryanezhad, 2010) (Akturk, 2011) (Askin, 2013) (Zeng, Tang, & Yan, 2014) (Houshyar et al., 2016)
Mixed Integer Linear Programming	(Das, Lashkari, & Sengupta, 2007) (Kia, Shirazi, Javadian, & Tavakkoli-Moghaddam, 2013) (Costa, Cappadonna, & Fichera, 2014) (Fahmy, 2016) (Aljuneidi & Bulgak, 2017) (Kuo & Liu, 2017) (Bychkov & Batsyn, 2017)
Quadratic Programming	(Srivastava & Chen, 1995) (H. Wang, Alidaee, Glover, & Kochenberger, 2006)

Cluster algorithm incorporates numerous assorted methods for identifying structure in a complex data set. Incidence matrix of machines is used for the array based clustering. This matrix represents handling necessities of parts of machines. Different clustering algorithms that have been proposed are Bond Energy Analysis (BEA), Rank Order Clustering (ROC), Rank Order Clustering 2 (ROC2), Modified Rank Order Clustering (MODROC), and Direct Clustering Algorithm (DCA). In Hierarchical clustering technique's, machine cells are formed employing a similarity or distance function between machines or parts and then machines or parts is detached into a couple of giant cells, every one of which is further subdivided into smaller groups. Common Hierarchical clustering technique that has been proposed is Single Linkage Clustering (SLC) algorithm. McAuley was the first author that applied similarity coefficient to solve the cell formation problems in 1972. The Rank Cluster (ROC) method was developed by King in 1980, which is designed to generate a diagonal grouping of the machine component matrix. McCormick in 1972 developed bond energy algorithm. In the machine component matrix, a bonding energy is formed between the pair of row elements and the column elements, which is the result of the connection pair of element values. The researchers, who used different clustering techniques to formulate the cell formation problem, are presented in Table VIII.

Table VIII. Clustering techniques and researchers

Clustering Technique	Researchers
Rank Order Clustering	(Murugan & Selladurai, 2007) (Amruthnath & Gupta, 2016)
Similarity Coefficient	(Witte, 1980) (Waghodekar & Sahu, 1984) (Gupta, 1991) (Seifoddini & Hsu, 1994) (Islam & Sarker, 2000) (Alhourani, 2013) (Raja & Anbumalar, 2016)

Heuristics and Meta-heuristics techniques provide an alternative basis for solving a cell formation problem. Although a heuristics technique does not insure for the optimum solution, they are beneficial in giving a feasible solution. In order to solve a wide range of optimization problems, particularly combined problems, metaheuristic techniques are used. Different algorithms that have been proposed are Genetic Algorithm (GA), Simulated Annealing (SA), Tabu search, Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO).

At first, Holland [1975] developed a methodology for GA that comprises an arrangement of steps, which are followed to move from one generation to another. Venugopal and Narendran in 1992 proposed a solution procedure based on GA for part-machine cell formulation. Kirkpatrick was the first researcher to use SA in 1983. SA, in fact, is the replication of the actual annealing process in which a system, at a higher energy level, is permitted to be cooled progressively in a controlled situation until it attains its lowest energy level. The researchers, who used different heuristic and meta-heuristic techniques to formulate the cell formation problem, are presented in Table IX.

Table IX. Heuristic and Meta-heuristic techniques and researchers

Heuristics and Meta-heuristics Technique	Researchers
Ant Colony	(Prabhaharan, Asokan, Girish, & Muruganandam, 2005) (Mak, Peng, Wang, & Lau, 2007) (Megala & Rajendran, 2013) (Li, Meng, Li, & Tian, 2016)
Bees Algorithm	(Pham, Afify, & Koc, 2007)
Discrete Bacteria Algorithm	(Liu, Wang, Leung, & Li, 2016)
Egyptian Vulture Optimization Algorithm	(Almonacid, Aspée, Soto, Crawford, & Lama, 2017)
Genetic Algorithm	(Sridhar & Rajendran, 1996) (Onwubolu & Mutingi, 2001) (França, Gupta, Mendes, Moscato, & Veltink, 2005) (Kulkarni & Shanker, 2007) (Wu, Chu, Wang, & Yan, 2007) (Pillai & Subbarao, 2008) (Aryanezhad, Aliabadi, & Tavakkoli-Moghaddam, 2011) (Taghavi-Fard, Javanshir, Roueintan, & Soleimany, 2011) (Saraç & Ozcelik, 2012) (Jamal Arkat, Farahani, & Hosseini, 2012) (Javadi, Jolai, Slomp, Rabbani, & Tavakkoli-Moghaddam, 2014) (Shiyas & Madhusudanan Pillai, 2014) (Jamal1 Arkat & Ghahve, 2014) (Halat & Bashirzadeh, 2015) (Darla, Naiju, Sagar, & Likhit, 2014) (Ghosh, Doloi, & Dan, 2016) (Saravanan, Karthikeyan, & Rajkumar, 2014) (Imran, Kang, Hae Lee, Zaib, & Aziz, 2016) (Suemitsu et al., 2016) (Jawahar & Subhaa, 2017) (Rezazadeh & Khiali-Miab, 2017)
Heuristic	(Harhalakis, Nagi, & Proth, 1990) (Mutingi, Mbohwa, Mhlanga, & Goriwondo, 2012) (Kumar & Sharma, 2015) (Raja & Anbumalar, 2016) (Hazarika & Laha, 2016) (Yang, Chen, & Long, 2016) (Bychkov, Batsyn, & Pardalos, 2017)
Particle Swarm Optimization	(Aghajani, Keramati, & Javadi, 2012) (Feng, Da, Xi, Pan, & Xia, 2017)
Simulated Annealing	(Venkataramanaiah, 2008) (Elmi, Solimanpur, Topaloglu, & Elmi, 2011) (Karthikeyan, Saravanan, & Ganesh, 2012) (Mohammadi & Forghani, 2016)
Tabu Search	(Logendran, Ramakrjshna, & Sriskandarajah, 1994)(Lozano, Adenso-Diaz, Eguia, & Onieva, 1999) (Chang, Wu, & Wu, 2013) (Solimanpur & Elmi, 2013) (Delgoshaei & Ali, 2017)

The Fuzzy-based approach answers the problem where parts whose heredities are significantly less bright. Fuzzy logic was invented by Lofty Zadeh in 1965. Fuzzy logic is interesting artificial intelligence (AI) tool as it gives a simple way to obtain the specific solution for a problem while utilizing vague or unclear input information. Chu & Hayya in 1991 uses the fuzzy C-mean algorithm to the cell formation problem.

Neural networks techniques commonly applied in cell formation due to their robust and adaptive nature. The application of neural networks to CM is comparatively new and has attracted the attention of a few researchers (Moon, 1990) (Karparthi, 1991) (Venugopal 1992) (Rao & Gu, 1993).

5. Discussions and future directions

The present study, talk about the literature survey of 170 articles on CM published during 1979 – 2017. Since the number of published articles on CM is vast and yet rising at a quicker pace, it was chosen for the investigation to think about the intensive arrangement of information for the better impression of history and the future research in CM.

- The magnificence of CMS is developing day by day on account of its useful outcome on the performance of the organization; this made to substantial development in published articles in different journals. In section 3, it is found that most of the research is taking place in cell formation. The accentuation appears to have been on evolving "new" methods instead of on assessing the present commitments. In most research, either matrix manipulation or mathematical programming has often been used to build cells. The majority of the cell formulations endeavor to make "independent" cells by reducing the number of parts processed in various cells. Different formulations address limiting the expenses of copying machines while a couple of attempts to create cells such as that capacity is balanced between and inside cells. Though, very few of them integrate all above objectives. From the perspective of applicability, justification, design and execution, Wemerlov and Hyer (1988) investigated research questions related to CMS. The majority of the problems rose by them need to explore and answer.
- The study found that conceptual and cell formation related approach constitutes around 51 % of total research articles. More attention should be given to layout, scheduling, loading, assignment, capacity planning, and related behavioral issues in CM. Consideration should also be given to integrated approach where different parameters are combining for optimum design and operate the CMS.
- Very little has been done to discuss flexibility in the manufacturing process for cell formation. "Cellular" production flexibility must be addressed as vital and prosperous competitive arms. In the presence of diverse machines, the reliability of machine tools is also a subject to study.
- There are significant numbers of cell formation techniques presented by different researchers. There is a need to evaluate and compare these techniques. Furthermore, these techniques must be verified to assess their performance in practical conditions. Cell formation method ought to incorporate documented and verified supporting software to simplify industrial applications. While mathematical model/ algorithm fit for tending to various aspects of CM have been developed, there does not exist an exhaustive framework to assess these calculations, and select the one that best suits the prerequisite of a manager.
- Findings of exact investigations on CM need to carried out which will undoubtedly be valuable to both academia and industry to propose a framework for its execution. Additionally, research can be done to propose optimal location of machines inside the cell considering facility layout.
- Empirical research is needed to assess the impact of CM in the real industry. There is a need to develop a relationship between CM implementation factors. There is also required to analyze barrier of CM implementation. Little attention has been paid to the key performance indicators (KPIs) analysis. There is a need to make the hierarchical structure to categorize KPIs and to identify and analyse the fundamental relationships between them. More comprehensive studies on the relationships between KPIs and their dependencies to supporting elements are needed. Multi criteria decision making methods like, AHP, ANP, ISM, DEMATEL can be used to identify and prioritize critical factors about CM implementation.

- Concerning authorship, in the study, it has been found that researchers from USA and India are more vigorous towards others in CM research. There is a need to poise the geographical dominion of the authors. There must be a joint effort among Institutes & Industries of created nations with developing and undeveloped nation to energize research in their region.
- There is a need to deploy CM to different manufacturing sectors, regular and non-customary businesses to enhance the overall organization performance. Exact research likewise should be done to learn whether CM is appropriate in unstable demand or not.

6. Conclusion

In this paper, an effort has been made to review the literature on CM. This paper compiles various reported definitions of cellular manufacturing and also presents a literature classification scheme focuses on research contribution, research methodologies, and problem-solving approach. Descriptive analysis of the research papers is also performed, and various cell formation techniques in cellular manufacturing are discussed briefly. Studying the extensive variety of research articles in CM, it can be inferred that the perception of CM mostly affects experts and academicians. The study suggested that there is a need to concentrate more on integrated approach where different parameters are combining for optimum design and operate the CMS. The study further proposes that the academicians need to cooperate with the industries to show signs of improvement come about and comprehend the CM implementation process. To fortify the results of the study, future researchers may take a still more significant sample size of articles to improve the outcomes.

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