Chapter 3
LITERATURE REVIEW

3.1 Optimum Design of Mechanical Elements
Since last ten years or so, it has been possible by researchers to employ the optimization techniques for design of mechanical elements because of the revolutionary developments in computer hardware and software.

3.1.1 Optimum design of Machine Tool Structures
A machine tool structure mainly consists of bed, column and arm. These structural members are optimized for dimensions (or weight, volume and material used) by many researchers with different objectives. This has been briefly mentioned in the following sections.

3.1.1.1 Optimum Weight of Structural Elements
Liew et al. (1990)[23] proposed an optimum design of thin plated box columns subjected to axial thrust and biaxial end moments. The design formulae based on an effective width approach are proposed and utilized for strength maximization. The solution is presented in non-dimensional charts useful for practical design. In the second phase, the minimum weight problem is solved with SUMT method. Results are expressed in terms of cross-sectional dimensions and minimum weights.

Ramana et al. (1984)[24] formulated the minimization of structural weight (of piano.milling machine) problem. The structure was idealized with triangular plate elements and three dimensional frame elements for FEM analysis. The constraints based on static deflections and principal stresses were developed. The solution of optimization problem was carried out using interior penalty function method of Davidon-Fletcher-Powell technique.

Rao et al. (1983)[25] idealized the radial drilling machine structure with frame elements and analyzed by using different combinations of cross-sectional shapes for the radial arm and column. The static rigidity and natural frequency requirements were satisfied. From the results, the best combination of cross-sectional shapes for the arm and column is suggested. Also, the minimum weight problem was solved using mathematical programming technique.
Sanghvi et al. (2010)[26] attempted application of genetic algorithm for the optimum cross section design of steel box column for pillar type drilling machine and compared the results with the existing results of DFP method. The agreement is satisfactory and the potentiality of GA is realized for a non-linear multi-objective optimization problem.

Reddy et al. (1978)[27] developed a computational capability for the automated optimum design of complex machine tool structures to satisfy static rigidity, natural frequency and regenerative chatter stability requirements. Mathematical programming techniques were applied to find minimum weight design of warren-type lathe bed and horizontal knee-type milling machine structures using finite element idealization. The lathe bed was optimized satisfying torsional rigidity and natural frequency requirements whereas milling machine structure is optimized with constraints on static rigidity of the cutter center, natural frequency and regenerative chatter stability.

Li et al. (2011)[28] modeled the 3-D solid structure of the column of the deep hole drilling machine using Solidworks. The weight of the column was optimized considering column thickness and inner rib thickness. Three optimal design methods were compared where the column stiffness and displacement were kept under control.

3.1.1.2 Optimum Stiffness and rigidity

The cutting forces acting on different parts of the machine tool need to be attended as they will result into deflection and high stresses. The stiffness and rigidity aspects are worked upon by number of researchers as following.

Makashi et al. (2005)[29] investigated the machine tool bed for optimum natural frequency and rigidity using neural network and FEM. About 4500 rib layouts were used to search the optimum one and it was shown that the time to search is less than 1/50 comparing with FEM. The estimation error of only 6% is seen.

Yuan S et al. (2013)[30] established the full parameterized FEM model to estimate and optimize the static and dynamic characteristics of machine tool bed using combination of BP neural network and genetic algorithm. It was shown that the method takes less time and is more precise compared to traditional method.

3.1.1.3 Miscellaneous Applications

Nakaminami et al. (2007)[31] analyzed the requirements of compound multi-axis machine tools based on functions to be carried out. A single compound multi-axis
machine tool functions as 2-axis CNC lathe and as a 5-axis machining center. It executes inclined surface machining and gear cutting as well. The authors discussed the systematic analysis and methodology to determine the compound multi-axis machine tool specifications from the quality and cost viewpoint. The relation of machine features, productivity and investment effectiveness with mechanical structures was presented.

Makashi et al. (2007)[32] attempted bed as machine tool structural element having ribs for optimum layout of ribs. The static and dynamic stiffness, natural frequency and thermal displacements were considered as evaluation functions. The use of neural network and FEM led to optimum layout with less than 4% estimation error. The value of evaluation function is improved as 18%.

Kushnir et al. (2001)[33] explored the feasibility of using polymer composites in machine tool structures in combination with conventional grey iron castings. A comparison and evaluation of different composite materials (solid harcrete, cast iron, cast iron filled with harcrete, cast iron with harcretelayer inside box section and along vertical walls, is presented assuming simplified geometry of machine tool structure as rectangular beams. The criteria of evaluation were (a) static stiffness of component under loading in different directions (b) specific stiffness i.e. stiffness to mass ratio (c) dynamic stiffness and damping (d) mass (weight) of component. The fourth and fifth were concluded to be overall best choice.

Heisel et al. (2011)[34] developed an algorithm and computer code for determination of possible machine tool structures configurations; on the basis of the relations between the movements of tool, work-piece and machine tool units by the machining. The configurations meeting the technical requirements are extracted and neural network is applied best solution.

The results of the operating tests of the developed neural network correlate with the manual calculations provided the structural extraction conditions are correctly formulated.

3.1.2 Optimum Design of Journal Bearings

The journal bearings are used extensively to support radial and axial loading in many applications. The design of journal bearing involves number of parameters and they are
to be properly taken care of to have satisfactory performance. The following description
briefly states the work carried out by many researchers.

**McAllister et al. (1983)**[35] presented optimum shape of steadily loaded one
dimensional journal bearing for supporting maximum load for a given minimum film
thickness.

**Hashimoto (1997)**[36] developed the optimum design procedure for high speed shaft
journal bearing operated in both laminar and turbulent flow regimes based on
mathematical programming. The simplified closed form design formulae were obtained
for eccentricity ratio, maximum film pressure, fluid film temperature rise, supply lubricant
quantity etc. The radial clearance, slenderness ratio and average viscosity of lubricant
which minimize the weighted sum of fluid film temperature rise and supply lubricant
quantity for various combinations of journal rotational speed and applied load were
determined by successive quadratic programming, a mathematical programming
method. From optimized results, the characteristics of optimized design variables in
both laminar and turbulent flow regimes were clarified.

**Lee et al. (1998)**[37] optimized the lubrication reliability and frictional loss of the
dynamically loaded journal bearing with R600a refrigerant application. For this, a
mathematical model was developed for analyzing the dynamics of the journal bearing
system with mobility method. In this method, the dynamically loaded journal bearing
problem is transformed into equivalent statically-loaded squeeze problem. Namely,
when a static load exerts to equivalent squeeze journal bearing, mobility of journal
center as dimensionless velocity to load parameter were stored in database by finite
element analysis. Thus the minimum film thickness and frictional loss of dynamically
loaded bearing were computed by mobility map equation of equivalent statically loaded
squeeze bearing. The mobility method takes into account the effects of the refrigerant
species aspect ratio, clearance ratio and surface roughness. It was concluded that
compared to R12, the frictional power loss and journal bearing size become smaller and
lubrication reliability is assured by design optimization.

**Yang et al. (2001)**[38] applied artificial life algorithm for optimum design of short journal
bearing. The design equations developed earlier were used and results were compared
with successive quadratic programming. The multi-objective optimization problem was
formulated with objectives of minimization of temperature rise and supply lubricant quantity. The 10 constraints presented were based on limiting values of clearance, L/D ratio, lubricant viscosity, film thickness etc. The results were presented for wide range of journal rotational speeds. The results when compared showed similar tendencies proving the use of artificial life algorithm as a strong and useful tool for optimum design of journal bearing.

Hashimoto et al. (2001) [39] presented optimum design methodology for improving operating characteristics of journal bearings and its application to elliptical bearings used in high speed rotating machinery. A hybrid optimization technique combining the direct search method and the successive quadratic programming is applied effectively to find the optimum solutions. The design variables were: vertical and horizontal radial clearances, L/D ratio, bearing orientation angle while the combined objectives were for oil film temperature rise, flow rate and inversion of whirl onset speed subjected to many constraints. When the results for wide range of speeds are compared, the effectiveness of present design is visualized.

Saruhan et al. (2004) [40] presented optimum design of tilting-pad journal bearing using GA. The multi-objective optimization problem was developed based on minimum film thickness, power loss and maximum film temperature. The constraints imposed were of film temperature, film pressure, lubrication flow, etc. The results of GA were compared with gradient based method and the feasibility and effectiveness of GA was demonstrated.

Matsuda et al. (2004) [41] proposed a criterion for optimizing the configuration of a fluid-film journal bearing by forming an optimization problem to minimize the altitude angle. The problem was solved numerically by the conjugate gradient method to yield a unique clearance configuration. The optimal clearance configuration was computed for various ratios of L/D of bearing. The designed bearing was compared with a full circular bearing in its configuration and static and dynamic characteristics. Moreover, a rigid-rotor system was used to verify that the designed bearing improves the onset speed of instability over a region of Sommerfeld number when it is compared with that of the full circular bearings.
Hirani et al. (2005)[42] presented a methodology for improving operating characteristics of fluid film steadily loaded journal bearings. The design variables such as radial clearance, length to diameter ratio, groove geometry, oil viscosity, and supply pressure are used to simultaneously minimize oil flow and power loss with three constraints (maximum pressure, temperature rise, and minimum film thickness). It was shown that increase in L/D ratio, oil flow, oil viscosity increases power loss. While feed pressure, clearance, and groove location have negligible effect on power loss.

Song et al. (2005)[43] presented use of enhanced artificial life algorithm (EALA) to compute the solution of an optimization problem for optimum design of high speed short journal bearing. The earlier published design equations were used for multi-objective functions of minimization of temperature rise and supply lubricant quantity. The design variables were clearance, L/D ratio, and viscosity. The constraints based on limits of radial clearance, L/D ratio, lubricant viscosity, and film thickness and pressure were employed. The computations were carried out using EALA for wide range of rotating speeds. It was shown that the EALA overcomes demerits of artificial life algorithm (ALA) considerably and ALA takes 10 times more than that of EALA calculation time. The relative variations of design variables with respect to wide range of speeds were presented.

Iwatsubo et al. (2009)[44] proposed an optimum design method of journal bearing for minimizing the total life cost inclusive of running cost and initial cost. The initial cost involves mainly the material cost (based on dimensions—length and diameter), production cost, while the running cost is related to the maintenance cost influenced by life time of the oil. The life of oil is presented in terms of oxidation (or temperature in bearing). The design variables considered were: bore, radius, and width of bearing as well as clearance ratio. The effects of diameter, width, and clearance ratio are presented in graphical forms. It was shown that when diameter and width are small, the cost decreases, as the speed of journal bearing will also be small, heat generation will also be less and temperature decreases. For the clearance ratio variation, the cost does not change much. The optimum values are decided by the constraints of maximum pressure and stability of the bearing.
Roy et al. (2013)[45] presented various arrangements of grooving location of two-groove oil journal bearing for optimum performance. Various groove angles considered were 10°, 20° and 30°. The Reynolds equation was solved numerically using finite difference method. The determination of optimum performance based on maximization of non-dimensional load, flow coefficient and mass parameter and minimization of friction variable was carried out using GA. The results of GA were compared with those of sequential quadratic programming. It was also shown that the optimum groove locations are not diametrically opposite as the usual practice and notion of convenience.

3.1.3 Optimum Design of Gears

Gears are widely used mechanical elements for power transmission. The design of gears is supposed to be optimized for volume and size of gearboxes.

3.1.3.1 Optimum Volume

Chong et al. (2000)[46] proposed and used genetic algorithm for geometrical volume (size) minimization problem of gear design of two-stage gear train for escalator and simple planetary gear train. The design factors such as strength, durability, interference, contact ratio, etc. are considered on basis of AGMA standards. The multi-variable non-linear minimum volume optimization problem was formulated with nine design variables and 22 constraints for two-stage gear train and four variables with 20 constraints for simple planetary gear train. The robustness and capabilities of GA were demonstrated with satisfying results.

The planetary gear transmission system becomes heavier and heavier with increasing power of the turbine. Since the lightweight and high reliability for such transmission system with working reliability and reduction in cost, it is needed to develop a model. It was shown that GA is better than conventional algorithm for solving the problems that have continuous, discrete and integer variables. Twenty two constraints for 2-stage gear train problem and 20 for simple planetary gear trains were formulated. For 2-stage gear train, the pitch diameter and face width was seen reduced by 40%.

Wei et al. (2013)[47] established a coupled non-linear dynamics model for planetary gear transmission system in wind turbine. The results showed higher reliability and considerable in volume.
Zhou et al. (2009)[48] presented a mathematical model for minimizing the volume sum of gear reducer using GA and MATLAB. It was shown that volume sum of gear reduces by 1.68% and similarly for the material and weight of reducer.

Qimin et al. (2010)[49] introduced the model for optimal design of planetary gear reducer with eight design variables and eighteen inequality constraints. The model was simulated on MATLAB to obtain minimal values of variables and weight of reducer. It was shown that Particle Swarm algorithm is practical in solving complicated problem of present type.

Tudose et al. (2010)[50] attempted a two-stage helical gear transmission minimum weight design problem (complete with the sizing and selection of shafts, bearings, housings, etc.) using a two-phase evolutionary algorithm. A set of 18 design variables with 24 constraints were employed for formulation of optimal problem. The formulation was solved using GA and SA leading to a comparison of mass saved vis-à-vis service life.

Tudose et al. (2008)[51] presented a complex and complete approach for optimal design of 2-stage helical gear reducer for minimum volume involving 11 design variables and 36 constraints in formulation. A 2-phase evolutionary algorithm was implemented for solution which yielded 18.787% reduction in volume. It was shown that the optimized design over and above saving the material and cost helps in saving space which could be efficiently utilized.

Buiga et al. (2012)[52] attempted a single stage helical gear unit optimal design for minimum mass using GA. The optimization problem was formulated with 11 design variables, 45 inequality constraints as every element of unit such as gears, shafts, radial seal, tapered roller bearing, shape of housing offers constraints. The two combinations of different materials for pinion and gear were considered. The mass reduction of 12.2% and 20.13% was achieved in comparison with traditional design.

Savsani et al. (2010)[53] made an effort to verify if any improvement is possible by using PSO and SA optimization algorithms used earlier for single stage spur gear design involving five non-linear constraints and five design variables. The ranges used for variables were expanded to investigate the best possible results which could be practically useful. Results showed that the weight is further reduced for expanded
ranges. Moreover, the refined design presented includes six (hardness as additional) variables and eight constraints.

**He et al.(2011)[54]** used MATLAB toolbox to optimize the developed model of two-stage helical gear reducer for mass minimization. The results showed the reduction of mass by 35.28% and center distance by 11.6% in mechanical design.

**He et al.(2009)[55]** described the optimal design of a reduction gearbox of a filling machine based on minimization of center distance. The contact fatigue strength, bending fatigue strength, condition of intervention and oil film thickness ratio of the gearbox were applied as constraints. The solution was attempted using MATLAB program and it was shown that center diameter of gearbox decreased by about 10%. The resulting decrease in weight and volume led to reduction of material and production cost.

### 3.1.3.2 Multi-objective Optimization

**Rosic et al.(2005)[56]** presented a procedure for single objective and multi-objective gear transmission optimization for each transmission stage of multi-speed gearbox in first part. The second part was for modeling of cylindrical gears using CATIA software and FEM was applied for these models. The volume minimization objective function was subjected to surface and volume strength constraints and the solution was sought by SUMT. The other stress restrictions were for tooth gear stress and contact stress.

**Mohan et al.(2012)[57]** presented optimum design of spur gear with multi-objectives of center distance, weight and tooth deflection minimization. The decision variables considered were module, face width and number of teeth on pinion. The bending stress and contact stress constraints were imposed for formulating the problem. The solution was achieved using GA for three materials namely cast iron, C-45 and alloy steel (15 Ni2 Cr1).

**Yu et al.(2012)[58]** established a mathematical model in order to accomplish optimal design of the most small reduction device of gear worm. The reduction device of gear has been widely used in industries, mining, enterprises and agricultural works. Because of the installation space limitations it requires to be designed optimally for small volume, reliable work, long life and low cost with ensured load carrying capacity. The developed mathematical model of objective function and constraints yielded the optimum results.
Li et al. (2010) [59] attempted a single stage cylindrical spur gear reduction gearbox problem for minimum center distance and gear face width using MATLAB toolbox. It was shown that the center distance reduces by 15% and objective of minimum weight reduces by 24.77%.

Wang et al. (1994) [60] showed a novel approach of modified iterative weighted Tchebycheff method to design the spur gear set with optimization of four objectives (center distance, weight, tooth deflection, gear life). The results are compared with previously published research.

Abuid et al. (2003) [61] performed an optimum design of two-stage spur gear system based on multi-criterion technique consisting of Min-Max method combined with direct search technique. Seven objective functions such as volume of gears, the center distance, five dynamic factors in input shaft, first teeth meshing, intermediate shaft, second meshing and output shaft. The objective functions were governed by 11 design variables such as number of teeth, face width of pinion of each stage, stiffness of input, intermediate and output shafts and inertia of four gears of mechanism. The results showed a compact gear system with quiet running compared with classical design.

3.1.3.3 Miscellaneous Applications

Savage et al. (1992) [62] described the optimization model for maximum life of spur gear with a compact algorithm of modified feasible direction search type. The designer has opportunity to change the mathematical optimum to a more practical design for comparative evaluation. Two examples were presented to illustrate the method and its application.

3.1.4 GA and PSO Applications

Das et al. (2002) [63] investigated application of real coded genetic algorithm to three different mechanical engineering design problems, viz., (1) volume minimization of a closed coil helical spring (3 variables, 10 constraints) (2) weight minimization of a hollow shaft (3 variables, 4 constraints) and (3) weight minimization of belt pulley drive (3 variables, 7 constraints). Based on implementation of GA to these problems it was shown that the performance of GA is better than other methods as the chance of getting global minima (or near to it) is far better. Also, since GA does not require gradient information of objective function, it is attractive to use. However, it was stated that the
performance of GA depends upon its parameter selection which should be properly done. The comparison of results with traditional techniques such as graphical and geometric programming revealed that GA offers better results.

Hu et al. (2003) [64] presented a modified PSO algorithm for engineering problems with constraints. The conventional PSO is started with a group of feasible solutions and a feasibility function is used to check if the newly explored solutions satisfy all constraints. All particles keep only those feasible solutions in their memory. The newer approach presented here to handle the constraints is simple and faster (saves computation time). Four benchmark problems namely (a) minimization of the total cost of pressure vessel (4 variables and 12 constraints) (b) welded beam for cost minimization (4 variables and 15 constraints) (c) minimization of the weight of tension/compression spring (3 variables and 10 constraints) (d) Himmelblau's benchmark problem (5 variables and 13 constraints). The results obtained for all these were compared with earlier published in literature and were found satisfactory and reliable.

Kazemi et al. (2011) [65] proposed a novel meta-model based optimization method which reduces the number of evaluations of objective functions and constraints considerably. This was achieved by building the proposed method on existing mode pursuing sampling method and incorporates strategies of (a) generating regions and (b) biasing generation of sample points forward feasible regions determined by constraints. The proposed method was tested with number of test benchmarks and design problems such as (a) minimization of weight of spring and (b) minimization of cost of pressure vessel. PSO has already been applied to many real world CNOPs with optimization tasks as varied as power system operation [Fuyukama et al., 2001], internal combustion engine design [Ratnaweera et al., 2002], biomedical applications [Eberhart et al., 1999] and welded beam [Eberhart et al., 2003].

Coath et al. (2003) [66] presented comparison of two constraint handling methods used in particle swarm optimization (PSO) to constrained non-linear optimization problems (CNOPs). Five benchmark functions are examined to assess the performance of each method in terms of accuracy and rate of convergence. The two methods, viz., (a) Penalty Function Method (PFM) and (b) Feasible Solution Method (FSM) were found to be extremely competitive. However, the rate of convergence of PFM was found to be
significantly faster than that of FSM in 2 out of 4 problems considered. In other two, the rates of convergence were comparable.

Chuang et al. (2004)[67] developed a hybrid swarm intelligence approach (HSIA) for solving complex optimization problems involving continuous, discrete, integer and zero-one variables. The method discusses the approach to handle various variables and constraints. A comparison of several benchmark problems of mechanical engineering design such as (a) design of gear train for optimum gear ratio (4 variables and 4 constraints) (b) design of pressure vessel for minimum cost of manufacturing (4 variables and 4 constraints) (c) design of coil compression spring for minimum weight (3 variables and 8 constraints). It was concluded that the developed HSIA algorithm is found to be superior to the existing methods both in solution quality and algorithm robustness.

The standard versions of PSO face a common problem of easily getting trapped into a local optimum when solving complex multi-modal problems and also lack an explicit mechanism to handle constraints that are often found in engineering optimization problems. Worasucheep (2008)[6] proposed a constrained PSO algorithm with the stagnation detection and dispersion mechanism that can detect a probable stagnation and is able to disperse particles to improve performance of constrained problems. The performance of the proposed algorithm is evaluated using three well-known engineering problems viz. (1) Himmelblau’s problem (5 decision variables and 6 non-linear inequality constraints, 10 boundary conditions) (2) welded beam problem for minimum cost (4 design variables, 7 inequality constraints) and (3) pressure vessel design for minimum cost (4 design variables). It was shown that CPSO-DD achieves consistently better results than other algorithms and solves the problem of being trapped into local optima in complex functions.

In order to examine the capability of soft computing (SC) methods in engineering design such as fuzzy logic (FL), genetic algorithm (GA) and artificial neural network (ANN), Saridakis et al. (2008)[68] extensively reviewed 156 papers on SC applications. Various hard to solve design tasks and issues were effectively addressed along with application of SC techniques. It was shown that SC gives considerable results and reveals a large scope of new research in engineering design.
3.2 Optimum selection using MADM methods

As discussed in Section 2.4, the Multi-Attribute Decision Making (MADM) methods are applied by large number of researchers for different cases. In the following sections, specific applications are mentioned in brief.

3.2.1 Optimum Selection of Material

Many researchers have worked on the applications of the said methods for many situations and also for developing new methods. Various approaches have been proposed in the past for optimum selection of materials. Ashby (2000)[69] proposed multi-objective optimization in materials design and selection using utility functions. Ashby et al. (2004)[70] provided a comprehensive review of strategies for selection of materials such as free searching based on quantitative analysis, checklist/questionnaire based on expertise capture and inductive reasoning and analog procedure. All of these methods use materials data in either computerized or non-computerized form. Shannian and Savadago (2006)[71] presented a material selection model using an MADM method known as ELECTRE. Matos and Simplicio (2006)[72] presented a practical example concerning the material selection to substitute polyvinyl chloride in automobile interiors.


Chauhan et al. (2012)[76] demonstrated the optimal selection of soft and hard magnetic materials using TOPSIS and VIKOR to arrive at the rankings. The (a) 16 soft magnetic material with 6 properties and (b) 24 hard magnetic material with 5 properties were considered. The relative weights for the different attributes were obtained using entropy method.
Edwards (2005)[77] discussed the issues surrounding the use of available materials knowledge and its implication on the quality of design decision making. Also, the list of questions for material selection presented is useful to the designers.

Maleque, Md.Abdul et al. (2010)[78] used digital logic methods to investigate for substitute of widely used brake rotor material cast iron by any other light weight material.

Fayazbakhsh et al. (2009)[79] proposed a novel method for scaling the material properties to overcome the shortcomings of modified digital logic method for material selection. Three cases of (i) ergogenic storage tank (with 7 materials and 7 attributes) (ii) human powered aircraft (with 12 materials and 6 attributes) and (iii) High speed craft (with 6 materials and 9 attributes) were considered for application of proposed method to show the efficiency of the method.

Chaterjee et al. (2012)[80] demonstrated the application of four preference ranking based methods such as PROMETHEE II, COPRAS-G, ORESTE and OCRA to gear material selection having 9 materials and 5 attributes. The results almost match for each method.

Manshadi et al. (2007)[81] proposed a new method based on well-known weighting factor approach combining non-linear normalization with modified digital logic method and verified the results obtained for two cases of cryogenic tank and human powered aircraft. The reasonable selections were achieved compared to questionable results of old method.

Rao (2008)[82] presented a logical procedure for material selection and applied the same to two examples. First is the material selection for metallic bipolar plates for polymer electrolyte fuel cell (PFEC) used in electric vehicles with 12 material options and each having 11 attributes. Second example is of the product to be operated in high temperature environment having 4 materials and 4 attributes.

Brifcani et al.(2012)[83] summarized the documented techniques for material selection with evaluation of them and compared methods for consistency and effectiveness.

Babu et al. (2006)[84] discussed the different material candidates for turbine blades and carried out optimum selection using TOPSIS. With selected optimum material, a CAD model of blade was generated and analyzed using FEM for different configurations.
(such as angles etc.). It was concluded that if the blades are of composite materials using carbon fibers, then they possess the high stiffness, low density and long fatigue life.

Gupta N (2011)[85] presented a material selection approach for selecting absorbent layer material for thin film solar cells (TFSCs) using MADM approach. Five materials with five properties of each were considered. Using TOPSIS, it was shown that the results (i.e. best option of CIGS material for TFSC) agree with experimental ones.

Findik et al (2012)[86] attempted the solution for best selection of materials for lighter wagon using weighted property index method. Here, five different properties were selected as required characteristics such as density, cost, specific stiffness, corrosion and wear resistance. The material candidates considered were ten based on aluminum, magnesium and titanium alloys. Aluminum alloys were found to be best and it was shown to save 98% weight saving over steel walls.

Jahan et al. (2011)[87] proposed a new version of VIKOR method which overcomes the main error of traditional VIKOR and showed that it can enhance exactness of material selection results in some biomedical applications where implant materials should possess similar properties to those of human tissues. Five examples such as (a)->?

Thakker et al. (2008)[88] considered a new way for optimal material selection strategy using combination of three well-known methods such as Cambridge Material Selector based method, adapted value engineering technique and the TOPSIS. The combination of strengths of each method streamlines the selection process. A case study of optimal selection of wave energy extraction turbine blade material is presented with eight material options and five attributes, (strength, specific weight, corrosion resistance, ease of maintenance, availability).

Jahan et al. (2010)[89] addressed to the issue of material selection, screening and ranking based on a list of questions about contribution of literature, methodologies or systems applied for material selection. It was shown that MADM has the potential to greatly improve the selection method. The two parts presentation include material screening methods such as cost per unit property, chart based, question based, AI and CAD based etc. in first part. The second part describes TOPSIS, ELECTRE, SAW etc. It was concluded that the traditional cost based approach or chart method cannot
guarantee that the selected material is the best because they limit the decisions in selection to only two or three criteria.

3.2.2 Optimum selection of Flexible Manufacturing System


3.2.3 Optimum selection of Robotic Components

Bhangle et al. (2004)[93] listed large number of robot selection attributes and ranked the robots using TOPSIS and graphical methods, comparing the rankings given by these methods. Rao et al. (2011)[94] proposed a method for robot selection (suiting particular application and production environment) having integrated subjective and objective attributes. The application of the method to three examples proved the potentiality of the proposed method.

Agrawal et al. (1991)[95] illustrated the rapid convergence from very large number to a manageable short list of potentially suitable robots using an elimination search routine. Subsequently the ranking of robots is presented using examples. Agrawal et al. (1992)[96] developed a comprehensive classification and coding scheme for grippers and illustrated the optimum selection of grippers using TOPSIS with the help of an example.

Khalid et al. (2011)[97] proposed an MCDM approach to select the most suitable scheduling rule of robotic flexible assembly cells (RFACs) using AHP and TOPSIS. Four criteria with four scheduling policies were examined.

3.2.4 Optimum selection of Miscellaneous Systems

Zoran et al. (2011)[98] applied AHP for selection of transport system in a mine for main haul corridor used for ore transportation. The corridor dimensions are 1800 mm long and having an area of cross-section as 11 m². The annual ore quantity transported through corridor is 7, 50, 000 tonnes.

Abdalla et al. (2013)[99] developed a method for optimum selection of a suitable layout for mine planning based on number of factors. Three different mine layouts were
addressed and the optimum mine layout was determined. **Dagdeviven M et al. (2009)**[100] attempted a weapon selection problem having high impact on defense systems using AHP and fuzzy TOPSIS method. **Prabhakaran et al. (2006)**[101] used TOPSIS for selection of optimum subsystem having 77 attributes electronic coding scheme.

**Goyal et al. (2012)**[102] proposed an approach to measure the machine reconfigurability and operational capability of a Reconfigurable Machine Tool (RMT). The multi-objective optimization problem was solved in two phases viz. application of Non-dominated Sorting Genetic Algorithm (NSGA) II followed by ranking of solutions using TOPSIS. The hybrid approach has great potential and is cost effective.

**Ashrafzadeh et al. (2012)**[103] presented a case study of warehouse location selection with successful application of fuzzy TOPSIS to a real problem of a big company in Iran. The criteria considered were 15 with five alternatives for best selection. **Chang et al. (2007)**[104] presented an evaluation of case study of digital video recorder (DVR) systems, a security product used for surveillance with AHP and ANP comparisons. The products of four firms were considered with 6 critical attributes.

**Ahluwalia et al.(1993)**[105] presented optimum selection of roller bearings based on 300 cylindrical roller bearings data and 100 tapered roller contact bearings using TOPSIS method.

**Athawale et al.(2010)**[106] presented a logical procedure for evaluation and optimum selection of a CNC lathe machine considering system specifications and cost using TOPSIS method. The 21 CNC lathe machines with seven criteria were considered for optimum selection or ranking. The weights were decided based on AHP. The results matched considerably with the existing ones in the literature.

**Savitha et al.(2011)**[107] used TOPSIS to choose the best network from available visitor networks for continuous connection by mobile terminal. Handover refers to the technique used to achieve the service continually in fourth generation wireless networks. Seven mobile nodes with four base stations were considered for TOPSIS to reduce the processing delays.

**Roldo L et al. (2012)**[108] examined the feasibility and the advantages of implementing water lubricated polymer shaft bearings and related the numerical model and software
application based on finite difference method. Different polymer based materials were considered for different attributes and compared with tin base Babbitt. The use of polymer based material indicated six times enhancement in power loss.

K. Maniya et al. (2010)[109] presented a novel Preference Selection Index (PSI) method to help decision-maker to select best alternative without deciding relative importance between attributes. Three problems were examined. Results comparison indicated the exactness for the suggested method.

Behzadian et al. (2012)[110] reviewed 266 scholarly papers from 103 journals since the year 2000 separated into nine different applications areas highlighting use of TOPSIS with other MADM methods. The second highest number of papers (62) are from design engineering and manufacturing systems.

Yurdakul (2004)[111] illustrated the use of AHP for machine tool selection and justified the application of ranking based on six attributes of four machines (3 vertical machining center and one conventional machine) of four machines each. The milling machines of a certain manufacturing unit of Turkey were considered for analysis and the final rankings were recommended to the management of the unit.

Prince et al. (2009)[112] proposed an n-digit alphanumeric coding scheme (a nomenclature which characterizes the MEMS products) on basis of n-attributes. A typical MADM approach is used and a 3-stage selection procedure was defined to make the methodology feasible and vibrant. The examples were used to demonstrate the suggested approach.

Maniya et al. (2013)[113] used AHP and PSI method for selection of optimal electrical energy equipment providing better energy economics and human comfort. A case study of domestic air conditioner is demonstrated to validate the proposed method and its potential applicability.