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Review Article

Optimization on Manufacturing Processes at Indian Industries Using TOPSIS

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Evaluation and optimization of multi-criteria with multiple alternatives have been essential activities for decision-making process. TOPSIS (Technique for order of preference by similarity to ideal solution), a multi-criteria decision-making (MCDM) technique, has been adopted in the past for research & decision-making and ranking of alternatives by optimizing input parameters to get the maximum overall output from the system. This study aims to explore the context, reasons, and particular advantages of using TOPSIS in the materials science and engineering field for realizing goals of competitive supply chains (SCs). This study has reviewed and analyzed research papers from the approach of systematic review of the literature. This study has presented a conceptual framework to emphasize the antecedents and consequences of using the TOPSIS methodology for output optimization in the materials science and engineering industry that can improve the competitiveness of SCs. This study found that TOPSIS based methodologies have been used in eleven types of industries in India, indicating the prowess of TOPSIS methodology. The results of TOPSIS have compared very well with other MCDM methods that are relatively more difficult and cumbersome. This study will help the engineers, practitioners, academicians, researchers, and SC managers with the application approach of TOPSIS for output optimization in various fields.

Keywords: Engineering, MCDM, Materials, Manufacturing, TOPSIS

1 Introduction

A manufactured product or a manufacturing process is defined for its quality by several characteristics or parameters. The parameters many-a-times conflict among themselves because some of them increase the overall quality of the product/process, and some decrease it upon enhancement in their levels and vice versa. For example, the input parameters of the Electric discharge machining (EDM) process affect the output responses like material removal rate (MRR), tool wear rate (TWR), and surface roughness (SR) in the machining of Al rein forced with SiO2 nano particles. The researchers observed that discharge current, pulse on time, and flushing pressure significantly affect the MRR, TWR, and SR[1]. In another example, the previous researchers have shown in their study the effect of mixing varying percentages of waste rubber shreds (0, 5, 10 & 15%) and cement (2 to 4%) in the soil to upgrade the soil properties for better shear strength, enhanced bearing capacity, and increased drainage[2]. These examples highlight that the input parameters of operating processes or the composition of materials affect the output results to a great extent. The desired output of one parameter may negate the effect of another parameter in achieving the overall quality of the product/process. In such a conflicting scenario of quality parameters, it has become desirable to optimize all the parameters simultaneously to have an optimum level of quality of the product/process. Multi-objective optimization has been the best decision-making methodology for selecting the optimal alternative/solution from a pool of solutions[3]. In multi-objective optimization, a trade-off is made among the conflicting objectives to achieve the optimal solution[4,5]. For example, in the case of the friction stir welding (FSW) process, the tool geometry and weld parameters significantly impact the welding quality that warrants optimization by using methods like Taguchi, TOPSIS, etc. to optimize the process parameters of FSW[6]. Kulshreshtha *et al.*[7] have shown in their study the impact of the angle of attack on the coefficient of drag force and coefficient of lift force for different profiles

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of National Advisory Committee for Aeronautics (NACA) aerofoil shapes by using Computational Fluid Dynamics so as to design an airplane or propeller for better fuel efficiency. A perfect combination of lift and drag is required to achieve the optimum level of energy consumption. Material selection and machinability of materials influence the quality and production cost of the industrial products to a great extent[8,9]. A single process parameter is insignificant to govern the quality of the output responses as the latter depends on the combination of input parameters. An optimum combination of process parameters optimizes the overall performance of the manufacturing system[10,11]. Optimization of a process depends on maximizing or minimizing some of the output variables by changing a set of input parameters[12]. Optimization of manufacturing operations is a necessity for cost competitiveness of products/services. Efficient and effective operational performance of individual firms is a must for any SC to remain competitive. The SCs have to deliver competitive products and services to the customers to survive in the market which requires cost effective manufacturing processes[13].

There are various hard materials used in the industry such as nickel-chromium super alloy, composites, ceramics, carbides, and tool steels. Precision machining of these materials is a very challenging task. Machining parameters need to be optimized for better quality of machined products at less cost[4,10,14–18]. Quality of machinig influences the productity of running equipment. For example, the efficiency of a diesel engine depends on the quality of the holes drilled in the injection nozzles[19]. TOPSIS can cater to optimization problems in an effective and efficient way[20–22]. It can be used in the decision-making scenarios involving finite material alternatives and a finite number of performance criteria that may be conflicting in nature[23,24]. It can analyze the effects of input parameters on the desired performance responses[24]. It has been used by researchers for selecting the ideal machining parameters[25]. It is an advanced MCDM technique with more scientific and simple mathematical approach that gives more accurate results in faster time as compared to other MCDM techniques[24,26–30]. In comparison to other MCDM methods, TOPSIS is a simple, computationally efficient, and easy-to-use method that accounts for the best and worst alternative solutions simultaneously for decision making[31]. TOPSIS can propose feasible solutions that are not possible through traditional statistical methods[31]. TOPSIS method produces better results with a small number of iterations than other similar optimization techniques like Particle Swarm Optimization (PSO), GRA, AHP, VIKOR, and Taguchi Method[24,30,32]. The basic thought in TOPSIS is to find a solution according to the closeness-coefficient between the feasible solution and the ideal solution[14,23].

MCDM tools have found tremendous utility in the industry for solving complex problems involving multiple criteria/objectives with conflicts among them. Decision-makers can choose the optimum solution from a set of alternative solutions[33]. Researchers have been using popular MCDM methods like grey relational analysis (GRA)[34], principal component analysis (PCA), TOPSIS, Deng's similarity method, and ELECTRE (elimination and choice expressing reality)[31]. Similarly, analytical hierarchy process (AHP) was introduced by Saaty to solve multi objective problems with conflicting criteria. Saaty defined APH as an MCDM technique which calculates the priority scales based on judgement by experts[35]. AHP uses the hierarchy system for decision-making with goal/objective at the top, criteria & sub-criteria in the middle levels and alternatives at the bottom. It can handle explicit as well as implicit attributes of a problem by using the experts' judgments[8]. Pair wise comparison of the hierarchy elements helps determine the priorities of criteria & sub-criteria concerning the goal and priorities of alternative solutions concerning the criteria/sub-criteria by using the Saaty scale of relative importance[36,37]. GRA technique can resolve problems by using complex interrelationships among the multiple performance characteristics. It can generate an idea about the system that is not visible and complete by handling incomplete information and opaque problems. In the GRA method, computation of the grey relational grade (GRG) decides the overall performance characteristic that makes a multiple response optimization (MRO) problem a single objective optimization (SOO) problem[15,31]. Taguchi method helps achieve the optimal solutions in a quick time in an economical way, thus improving productivity at a low cost. This method enhances the product quality with a robust system design by optimizing design parameters using statistical methods. It uses statistically designed orthogonal arrays for conducting a limited number of experiments to analyze many decision parameters.

This approach makes Taguchi an economical and less time-consuming method[38,39]. Taguchi primarily solves SOO problems[31,33,40]. An SOO problem fails to account for the interaction among multiple objectives, which is its limitation restraining its utility for MRO problems[31]. Taguchi method gives different optimal solutions for each attribute while the TOPSIS method gives a single optimal solution for all attributes[41].

Design of experiments (DoE) is a statistical tool to identify the significant input variables impacting the output variables and also the extent of their impact[42]. DoE uses an orthogonal experimental design plan for conducting the experiments to identify the optimal combination of input variables[10,43]. System analysts, engineers, and designers use the DoE as it is a powerful technique for designing multi-variable experiments[44]. VIKOR methodology is widely used in many fields for ranking the alternative solutions[45]. VIKOR stands for 'VIse Kriterijumska Optimizacija Kompromisno Resenje' in Serbian which translates to Multi Criteria Optimization and Compromise Solution. The closeness of the alternatives to the ideal solution decides their relative ranks[45]. VIKOR determines the optimal combination of parameters for optimization of performance responses[11].

Based on the insights garnered from literature there is a necessity for a comprehensive review study on TOPSIS to show its usefulness and contribution in research in material science and engineering sector in India because supply chains can become more productive only with optimum utilization of resources. The objectives of this study are to understand the contexts and reasons for application of TOPSIS technique in material science and engineering by adopting a systematic literature review approach. This study aims to provide a conceptual framework of using TOPSIS in materials science and engineering.

2 Materials and Methods

This study presents a review of research articles on TOPSIS based methodology used in materials science and engineering. Scopus, Google, and EBSCO databases were searched electronically to select and collect good-quality research articles. The selection criteria were as follows: (1) Publishing of articles during 2005-2021, (2) Articles published in English language only, (3)Articles discussing or explaining the antecedents for using the TOPSIS technique for materials science and/or engineering research in the Indian engineering industry. A systematic search approach was adopted to identify the research articles. The above method involved searching keywords in the title, abstract, and keywords section of the database (Scopus, Google, and EBSCO). The keywords used (in several combinations) were: "topsis", "technique", "for", "order", "of", "preference", "by", "similarity", "to", "ideal", and "solution". Based on the keywords,4347 articles were identified. In the subsequent search step, only the studies of document type "articles" published in the English language in affiliate country India were included. This process produced 520 articles. In the next step, the subject area of "Engineering" was chosen which generated 245 articles. In the next selection step, only articles of source type "Journal" were selected which produced 243 articles. Journal articles are preferred for reliable information and accurate results[46]. In the second last step only articles with exact key word "TOPSIS" were selected which finally produced 122 articles for our study. In the last step only articles which were related to materials science and engineering using TOPSIS were selected based on review of titles and abstracts. All articles were then checked for duplication. Only one paper was found duplicate which was excluded from analysis. A review panel of experts was established to review/advise on the selected articles for inclusion/exclusion in the review study[47]. The review panel comprised two supply chain management professionals, two mechanical engineers from engineering industry, and two professors in operations management. All the panel experts had a minimum of five years professional experience in their work domains. After review of articles and concurrence by the panel members, finally the authors selected 77 valid articles for this study. Details of the exclusion and inclusion criteria are given in Table 1.

This study is a systematic literature review (SLR) based on within-research study and between-research study literature reviews and analyses which are essential for all literature reviews. In a within-research study literature analysis cum review, the entire content of a particular article is reviewed & analyzed in detail. A between-research study literature review process compares information between two or more research studies to disclose the similarities and differences between those research studies[48]. SLR is an efficient and reliable approach for reviewing and analyzing the existing literature[46].

Table 1 — Selection criteria of articles for study

Inclusion	Exclusion
Published journal articles	Books, conference proceedings, editorials, viewpoints, newspaper articles, working papers
Full text available	Full text not available
English articles	Non-English articles
India as affiliate country	Affiliate country other than India
Subject area of Engineering	Subject area other than Engineering
Articles using TOPSIS methodology	Articles not using TOPSIS methodology
Articles related to materials science and engineering research	Articles using TOPSIS methodology related to social science research

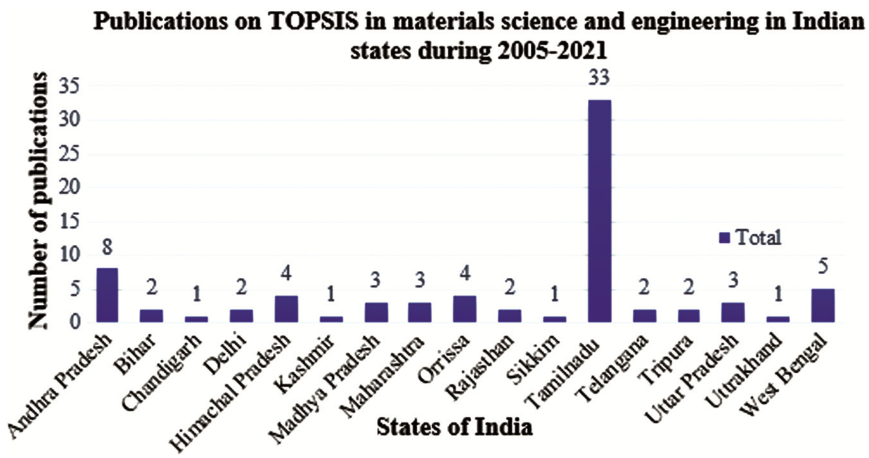

Fig. 1 — Publication of articles in various states of India during 2005-2021.

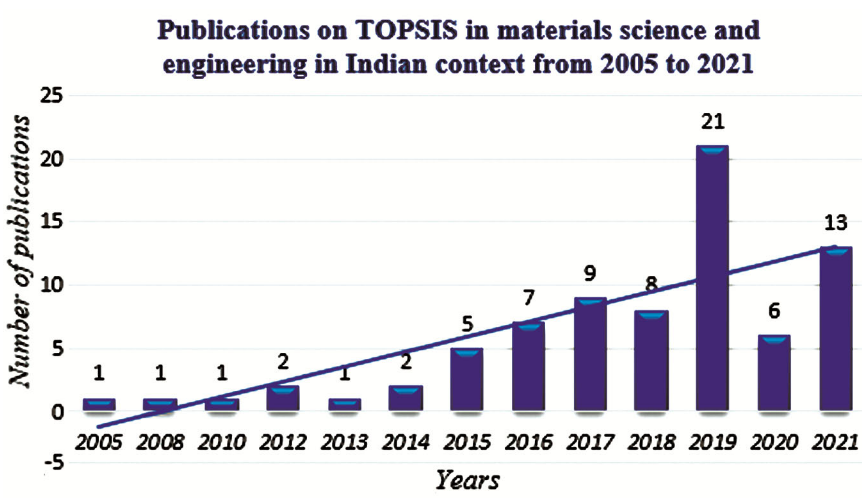

Fig. 2 — Trend of publication of articles in Indian context.

2.1 Significance of TOPSIS in manufacturing industry

TOPSIS has been used by researchers in various states of India between 2005 to 2021 as is seen in Fig. 1. Sixteen out of 28 states and 1 out of 8 union territories of India have published the articles covered in this study which signifies the usefulness of TOPSIS across India. Tamil Nadu state is the leader in publications with 33 articles followed by Andhra Pradesh with 8 and then West Bengal with 5 publications. There is a large scope of further publications of articles as many states and union territories in India with reputed educational institutions are yet to adopt TOPSIS in research and development in material science and engineering.

An increasing trend is observed for publications on TOPSIS in engineering and materials science in Indian context during 2005-2022 as depicted in Fig. 2. The publication of articles of this study started with just one article in 2005 and the number remained within a narrow range of 1 to 2 till 2014 which is a long gap of 9 years. The publications started increasing from year 2015 with five articles and reached the peak in 2019 with twenty one articles. There was a sudden drop in 2020 with just six publications. In 2020 the Coronavirus (COVID19) pandemic had caused panic in all sectors including education. This pandemic might have caused the drop in publications in 2020. In 2021 the number of publications increased more than 100% probably due to vaccination program of government and ease of lockdown restrictions on educational institutes. The trend line in Fig. 2 is indicating the growth of publications in coming years.

The articles were segregated on the basis of the industry to which the article's product or material belonged. Fig. 3 shows the articles on the basis of industry sector. TOPSIS based methodologies have been used in eleven types of industries in India with focus on materials science and engineering research. Metal processing and machining industry accounted for maximum number of articles i.e. 52 (~67% of total), followed by Energy sector with 10 articles (~13% of total), Polymer with 4 articles (~ 5% of total), Electronics with 3 articles (~4%), and Forging with 2 articles. Balance articles were contributed by Additive Manufacturing, Construction, Textile, Water, Material Handling, and Process industry with one article each.

TOPSIS, AHP, and Grey-based Taguchi methods were used by[36] to perform multiple objective optimization of parameters of Fused Deposition Modelling (FDM) additive manufacturing process to produce an end-user product for automotive industry. TOPSIS was used by[49] to determine the optimal mix proportions of bagasse ash blended high performance concrete. TOPSIS was used by[4] in combination with

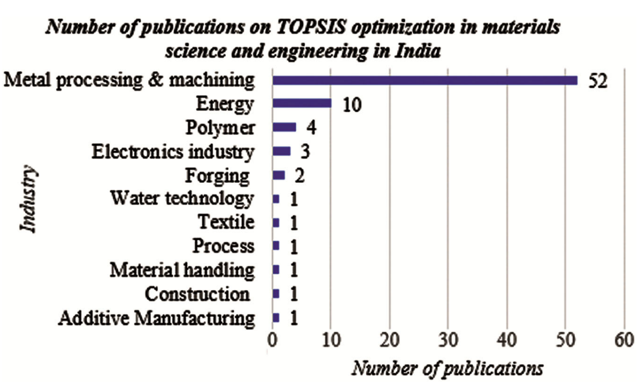

Fig. 3 — Industry wise publication of articles in Indian context.

TAGUCHI method to determine the optimal combination of input parameters of Rotary Tool Micro Ultrasonic Drilling (RT-MUSD) process for drilling of silicon for achieving maximum MRR, minimum taper angle, and minimum hole overcut simultaneously. The optimal combination of parameters improved the overall performance of RT-MUSD process by 26%. Ashby's approach, TOPSIS and VIKOR methods deployed by[50] produced the optimum solution for selecting the best bridge material of shunt capacitive RF-MEMS (Radio Frequency Micro Electro Mechanical Systems) switches. The results obtained from the three methods showed good agreement with each other in the selection of optimum material. Optimization of the given criteria of low pull-in voltage, low RF loss, high thermal conductivity, and maximum displacement of the beam structure helped achieve the optimal input parametric combination. The optimum solution suggested gold and copper as the best bridge materials, but copper was selected finally for the economical production of switches. TOPSIS and VIKOR were used by[45] for selecting optimum dielectric materials of RF-MEMS switches. Both the methods gave the same results by selecting titanium di-oxide (TiO2) as the best dielectric material. Fuzzy TOPSIS was used by[51] to rank the problems of forging industry. 'Lack of Pollution Control Initiatives' was found as the most prominent problem to attend to by the organizations. AHP & TOPSIS were deployed by[26] to evaluate the optimum set of forging process parameters for minimizing the rejection rate of forgings. AHP & TOPSIS were used by[52] to rank cotton fibers based on their quality. They considered important cotton fiber properties and evaluated their relative priorities using the AHP method. TOPSIS and PROMETHEE-2 methods were used by[27] for the evaluation of viabilities of five desalination technologies, namely electro-dialysis (ED), reverse osmosis (RO), vapor compression (VC), multiple effect distillation (MED), and multi-stage flash (MSF), for a community-based application.

Fuzzy AHP & fuzzy TOPSIS methods were used by[53] to evaluate and rank the alternative locations of a new thermal power plant in central western part of India based on their overall performance in satisfying the criteria of social, technical, economic, environmental, and political factors. ANP, TOPSIS and VIKOR were tried by[54] to evaluate and select the best biodiesel blend fuel to achieve the maximum engine performance and environmental benefits by reducing noxious emissions. TOPSIS was used by[12] in a pilot experimental study of hydrogen-diesel dual-fuel for optimization of output responses of Brake thermal efficiency (BTE), Soot (measured in FSN- Filter Smoke Number), and nitrogen oxides (NOx). These output variables are of pivotal significance for analyzing the performance and emission indices of the dual-fuel operation. The experiment results showed the dependency of the optimal performance-emission trade-off spectra on the optimum tuning of the input parameters. They found the optimal solution corresponding to BTE value of 29.97%, NOx 1063.27 ppm, and Soot as 2.224 FSN at 20% load condition with the first injection strategy of hydrogen (H1). Hybrid Entropy-TOPSIS method was used by[55] to determine the optimum set of design parameters of a jet impingement device for achieving the highest overall performance of the system by considering the performance criteria. This methodology provided the ranks of alternative solutions that did not change upon changing the criteria weights during sensitivity analysis of the performance criteria. They compared the TOPSIS results with VIKOR, POROMETHEE-II, PSI, and GRA methods. The results of all these methods showed the same alternative as the highest among all the alternatives. By using Preference Selection Index and TOPSIS approaches[56] found the optimal set of parameters (size of silt particles, concentration of silt particles, velocity of jet, and working time) which offers the highest performance (min. weight loss, max. efficiency, and min. normalized wear) for the Pelton turbine. TOPSIS with GRA was used by[57] for MRO of Aegel Marmelos (AM) pyrolysis experiment for getting the maximum bio-oil yield from AM de-oiled seed cake. Bio-oil produced by the AM process can blend with diesel to meet the increasing fuel demand and with reduced NOx emissions. Both the methods (TOPSIS and GRA) gave a similar optimal solution to obtain the maximum bio-oil yield. Fuzzy AHP with Fuzzy TOPSIS was used by[58] for optimum selection of 100W solar panel and found the integrated methodology effective as it removed the subjective evaluation of vague sub-criteria in selection of solar panels.

TOPSIS was used by[59] for optimizing engine input parameters which could result in maximum efficiency and minimum emissions. The study involved six types of fuels without FeCl3 additive, six fuels with FeCl3 additive, different operating loads, two types of fuel injection methods- homogeneous charge compression ignition-direct injection (HCCI-DI) and Direct Injection (DI). The optimum engine parameters were found as FeCl3 nano-additive blend fuel with Direct Injection (DI) combustion at 25% load. TOPSIS was used by[60] for determining the optimum setting of diesel engine process parameters (Compression ratio (CR), Fuel injection timing (FIT), Air temperature (AT), Air pressure (AP)) for optimization of diesel engine performance and emission parameters. TOPSIS was used by[61] to find the optimum glazing material for solar thermal devices. They found Polysulfone material as the best material among the seven alternatives for the maximum satisfaction of the given input conditions.

Transportation and logistics are very critical aspects in the SC operations. TOPSIS & AHP were used by[62] to select the optimally best conveyor belt material by optimizing the multiple requirements and conditions. AHP and TOPSIS were used by[63] for selecting an optimum Condition Monitoring system from amongst Visual inspection, Vibration analysis, thermography, acoustic analysis, and ferrography by optimizing the multi criteria of Diagnostic Quality, Quantity of failure which can be measured, Cost, Supportability of diagnostic method, and Environmental interference. TOPSIS was utilized by[64] to select the best epoxy based composite material which could optimize the multi criteria of application. TAGUCHI and TOPSIS methods helped[41] select the optimal set of machining variables for end milling of epoxy granite composites to optimize the performance responses of thrust force, tangential force, and SR. During confirmation testing they found a deviation of 4.46% in SR and a deviation of 17.24% in thrust force from TOPSIS results. These confirmation results indicated consistent optimization through TOPSIS method. Optimal cutting conditions were determined by[65] with TOPSIS method for trimming of carbon fiber reinforced polymer composite so as to generate minimum tool wear, SR, and tool temperature simultaneously while maintaining high production rates. They found the TOPSIS optimum conditions as valid in the confirmation tests. AHP & TOPSIS were used by[66] for MRO of milling process on FRP composite material.

3 Results and Discussion

The authors of the research articles that were eviewed in this study, had used TOPSIS either solely or in combination with other MCDM methods. The maximum studies (~31% of total) had used only TOPSIS (refer Fig 4). Clubbing of purely Fuzzy TOPSIS articles with purely TOPSIS articles resulted in 24 articles constituting about 36% of the total articles. The study revealed that various researchers had used different methods like AHP, Entropy, SIMO's procedure, etc., to obtain the performance criteria weights. TOPSIS found TAGUCHI as the best friend in many articles. Researchers had used TAGUCHI along with TOPSIS in 17 (~22% of total) articles. This study found five research articles in which researchers had utilized TAGUCHI and GRA with TOPSIS for validating TOPSIS results. VIKOR and TOPSIS appeared together in 4 research articles. Researchers had used the Fuzzy set theory in 5 research articles to avoid any uncertainty. The researchers had utilized TOPSIS and GRA together with other MCDM techniques in 11 research articles. Other MCDM methods like PROMETHEE-II, PSI, RSA, RSM, DFA, MOORA, etc., were also used along with TOPSIS but at a low scale.

3.1 TOPSIS usage in Manufacturing industry

Machining is an energy intensive operation in an engineering industry and hence there is a need for optimization of machining parameters to achieve the desired output. Product quality depends a lot on machining process. TOPSIS & AHP were used by[3] for choosing optimal non-traditional machining (NTM) process to optimize the combined criteria of a specific material and a unique shape feature. AHP, TOPSIS and GTMA (graph theory and matrix approach) methods were used by[8] for optimizing multiple criteria to select an optimum welding method from a set of alternative welding mechanisms for a ship manufacturing activity. TOPSIS was utilized by[67] in combination with desirability functional analysis (DFA) and fuzzy set theory to optimize the operating parameters of electro chemical machining process (ECM) for titanium alloy (Ti6Al4V). It was used by[68] with the Entropy weight method to find the optimum combination of input variables of EDM process to machine Al–12% SiC metal matrix composite (MMC) material. It was utilized by[69] to select optimal EDM process parameters of machining Al-Cu/TiB2 in-situ MMCs. It was used by[70] for Gas Tungsten Arc welding (GTAW) parameters optimization for welding of AISI 904 L super austenitic stainless steel joints. It was used by[71] with Simo's procedure of criteria weighting for MRO of Abrasive Water Jet cutting process variables in machining AA5083-H32 alloy. TOPSIS and AHP were used by[72] for MRO of turning process for machining EN25 steel with Physical Vapour Deposition and Chemical Vapour Deposition coated carbide tools. DFA and TOPSIS were used by[73] to find the optimal set of input variables of the Wire EDM (WEDM) process for machining Inconel 600. Fuzzy AHP and fuzzy TOPSIS were used by[35] for MRO of machining AISI 1040 steel with coated tools. Taguchi based GRA and TOPSIS were used by[38] for optimization of machining parameters for turning 15-5 PH stainless steel. Grey-based TOPSIS was selected by[5] for MRO

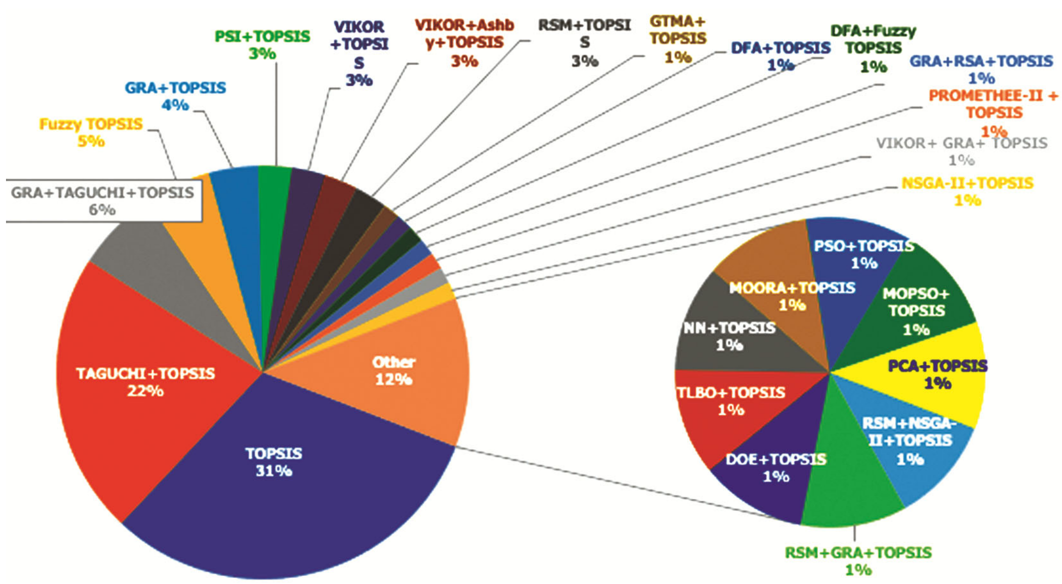

Fig. 4 — Frequency of usage of MCDM methods in articles.

of friction welding (FW) of Al/SiC (aluminum–silicon carbide) MMC. This approach increased the performance index of attributes at the optimum setting of parameters. TOPSIS and GRA were used by[74] for MRO of powder mixed EDM (PMEDM) process using chromium powder mixed to the dielectric fluid to machine H-11 die steel. TAGUCHI-based GRA and TOPSIS were adopted by[15] to select the optimal set of input variables of the SiC PMEDM process for machining H-11 die steel. TOPSIS was used by[75] for MRO of micro EDM process for machining AISI304 steel and observed the improvement in overall performance level of the process at optimum setting. GRA, RSA, and TOPSIS methods were used by[39] to know the optimum combination of turning process parameters for dry condition turning of Magnesium alloy AZ91D using polycrystalline diamond cutting inserts. GRA and TOPSIS were used by[31] to find the optimal set of input variables of reinforcement, grain size, and blade angle of the Gas Protected Stir Casting process to optimize the combined output variables of tensile strength and micro-hardness. Gas protected stir casting process was used to develop Al2024/red mud composite. PSI and TOPSIS methods were used by[10] for parametric optimization of WEDM process for machining EN31 Tool Steel.

Integrated Taguchi and TOPSIS method was used by[33] to explore optimal input variables for the turning process of EN25 steel using coated carbide tools. They found the optimum combination of machine parameters quite encouraging. Researchers have used TAGUCHI orthoginal designs frequently for experimental studies. Optimal FW condition for Al/SiCp was determined by[18] by using Taguchi principles integrated TOPSIS approach. They found significant improvement in the signal-to-noise ratio of optimum solution. TAGUCHI, AHP and TOPSIS methods were used by[19] to determine the optimum setting of cryogenically cooled micro-EDM drilling process on AISI 304 steel. They discovered an improvement in performance responses by operating the machine at the optimum combination of process parameters. TOPSIS and TAGUCHI methods were used by[14] to select the optimum setting of EDM process for machining D2 tool steel. TAGUCHI, AHP, and TOPSIS methods were used by[76] for MRO of EDM process by using carbon nano-tube (CNT) infused copper electrode for machining D2 tool steel. They observed that optimal settings had improved the overall performance of responses. They also found TOPSIS an accurate method for MRO problems. TOPSIS & TAGUCHI methods were utilized by[20] to optimize the parameters of laser micro-drilling of nickel based super alloy coated with thermal barrier coating.

Operation at optimum settings resulted in 19% improvement in SR and 12% reduction in surface crack density. TOPSIS + TAGUCHI+GRA methods were used by[77] to optimize the end milling parameters on Magnesium (Mg) Hybrid MMC. TOPSIS was used by[78] for MRO of electrochemical micromachining (ECMM) of Has telloy. TOPSIS and the Teaching-Learning Based Optimization algorithms were used by[79] for maximizing MRR and minimizing SR simultaneously and finding the optimal set of input variables of the end milling process for machining titanium alloy Ti-6Al-4V. TOPSIS and Particle Swarm Optimization (PSO**)** methods were used by[16] for MRO of nano-fluid minimal quantity lubrication (NFMQL) assisted turning of titanium (grade-2) alloy and found the methodology as very effective. TOPSIS was used by[17] for MRO of WEDM process for machining aluminium alloy composite.

Aluminium alloys and tool steels were used for machining experiments by many researchers. TOPSIS method was applied by[80] to find the optimal set of input variables by optimizing the output responses of the EDM process for machining the AISI D2 tool steel. It was used by[81] to determine the optimum machining parameters for turning aluminum alloy Al 7075 using Al2O3 nano-cutting fluid. It was used along with Taguchi method by[82] for optimizing the FSW process parameters to obtain maximum ultimate tensile strength (UTS) and micro-hardness (mH) individually and simultaneously. RSA, NSGA-II & TOPSIS were used by[25] to determine the optimal setting of milling operation of Inconel 690 using castor oil as a lubricant. They observed less than 1% error between the predicted and the experimental results of output responses. TOPSIS was used by[83] to determine the optimal combination of input variables of the ECMM process for machining SS304 alloy steel with polymer graphite electrode using sodium nitrate as the electrolyte. They observed an enhancement in multi-response characteristics of ECMM of SS304 alloy. TOPSIS was used by[84] to find the optimal process parameters for FSW of dissimilar aluminium alloys AA6061 & AA5183.

TOPSIS with DoE was used by[85] for exploring the optimal set of input variables of silicon carbonitride

(SiCN) thin film deposition process for laying thin film of SiCN on a metal surface. They observed an enhancement in overall performance by using the optimum settings. Response Surface Methodology (RSM) and TOPSIS were used by[86] in their MRO study of plasma arc cutting of Monel 400 super alloy and found the approach as very effective for determining the optimal parametric settings. TOPSIS was used by[28] to optimize the variables of electric discharge coating process to obtain maximum deposited layer thickness and minimum SR.TOPSIS was used by[87] and[88] for MRO of turning process of aluminium alloy MMC Al7075 and AISI-D3 tool steel respectively. Ranking of various aluminum alloy based composite materials was done by[9] using AHP-TOPSIS, Multiobjective optimization on the basis of ratio analysis (MOORA) and MOORA (reference point method) for optimization of physical, mechanical, and tribological properties. They found similar results by using all these MCDM techniques. This proves the effectiveness of TOPSIS method. TOPSIS was used by[89] for optimization of input parameters of the electrical resistance spot welding process on AISI 1020 Steel.

TOPSIS and VIKOR methods were used by[90] for optimization of EDM process parameters for machining of aluminium alloy 6061-cenosphere MMCs. TAGUCHI-TOPSIS approach was adopted by[91] to find the optimal settings of input variables of boron carbide PMEDM process for machining Inconel X-750 alloy. They observed less than 7% error between estimated and measured values of performance responses by operating the machine at the optimum settings. RSM and TOPSIS methods were used by[92] for MRO of Abrasive Aqua Jet Machining process for cutting of aluminium alloy 7075 MMC. During confirmatory testing, they found less than 5% error between estimated and actual values of performance responses at the optimized setting of input parameters. TOPSIS and PCA methods were used by[93] for MRO of FSW process of aluminum alloy AA 6061-T6 for three types of tool geometries separately and selecting the best (optimum) tool geometry. They found the same optimum settings of input parameters for three types of tool geometries. The confirmation test of optimized parameters for all the tools found the measured results within acceptable limits.

TOPSIS method was used by[21] to choose the most optimal solution from the set of non-dominated Pareto optimal solutions given by the multi-objective PSO method. TOPSIS solution gave the optimal set of input variables of the EDM process for machining mild steel with Cu-MWCNT composite coated 6061Al electrode. TOPSIS, GRA & VIKOR methods were adopted by[11] to select optimal process parameters of ECMM process for micro holes generation on the copper work material. TOPSIS method was utilised by[94] to select the optimal set of the input variables of EDM process for machining of Silicon Carbide (SiC) and Boron Carbide (B4C) particles reinforced Al-6061 hybrid MMC. Taguchi based TOPSIS methodology was adopted by[95] to select optimal process parameters of WEDM process for machining AA7075 composite material. Optimization of the process parameters of EDM of Al-2050 alloy was done by[96] by using TOPSIS & GRA with different rotating tools. TOPSIS was utilized by[97] to optimize the machining parameters for turning of AISI 52100 hardened steel.

3.2 Advantages of TOPSIS over other MCDM methods

TOPSIS is a systematic, efficient, and very effective method for ranking alternatives in MRO studies. It can produce results with more accuracy. Many MRO studies have used TOPSIS with successful results. TOPSIS involves fewer computational steps when compared to other MCDM tools such as Artificial Neural Network, Genetic Algorithm, and GRA. TOPSIS working with other MCDM techniques can be highly effective and efficient in MRO studies. Conventional optimization tools are cumbersome to work with for MRO studies. The most effective approach for optimization is to transform a multiple-objective problem into a single-objective problem. TOPSIS is an evolutionary & convenient algorithm to handle the single-objective problem effectively and efficiently. TOPSIS considers all the explicit and implicit variables of a problem systematically & logically to produce the most optimal solution for a given MRO problem. Some researchers had used TOPSIS scores to develop the regression-based model of relationships between input variables and output variables of a process. Several studies had confirmed the validity of the TOPSIS optimal solutions through confirmation tests that showed an overall improvement of system performance values. Several researchers found the TOPSIS based predicted results within acceptable limits of deviations during confirmation testing which substantiates the utility of the TOPSIS approach in multi-criteria optimization problems.

This study found that a single process parameter does not influence the performance of a process significantly on its own; rather, the quality of the performance responses depends on the combination of the input variables of the process. For this fact, the MCDM technique of TOPSIS is the best method for finding the best optimal sequence of input parameters. Researchers can use TOPSIS to resolve complex situations by optimizing any number of attributes and selecting the best alternative from a pool of many alternatives. In the last decade, many researchers have used TOPSIS in their MRO studies either solely or in combination with other methods like GRA, VIKOR, TAGUCHI, PSO, Ashby, PCA, etc. Evaluation of criteria weights is most important for using TOPSIS. Researchers had used various methods in their studies like AHP, entropy method, genetic algorithm, fuzzy AHP, ANP, SIMO's procedure, etc. for establishing the weights for the criteria.

3.3 Findings of the study

TOPSIS method has compared well with other MCDM techniques like GRA, VIKOR, MOORA, etc. in many studies. In thirteen studies the researchers found the same optimal combination of process parameters by using TOPSIS and other MCDM methods. In one study the ranking results were the same by using TOPSIS, VIKOR, and GRA. Three studies found the deviation of TOPSIS results from that of other MCDM techniques. In such cases, it might be useful to do the confirmation test with a third MCDM method to arrive at accurate conclusive solutions. These findings reflect the credibility, robustness, consistency, and reliability features of the TOPSIS methodology.

Researchers had adopted TOPSIS method for various reasons: to find the optimal settings of machines because the machining involves multiple criteria with multiple alternatives of different combinations of machine settings, to select the optimum material for specific applications, to improve the accuracy of results, because of the drawbacks and limitations of existing techniques for optimization, to fill the research gap because TOPSIS had not been utilized by past researchers in the specific problems, because TOPSIS is quite simple in conception and application compared to other methods for MRO, computational based investigation through TOPSIS enables an in depth sensitivity analysis and institutes a cost efficient research platform, etc. Twenty-two studies (~28% of total studies) used TOPSIS for obtaining the optimal solutions. There was no mention of any specific reasons for usage of TOPSIS in these twenty-two studies. This fact points towards the reliability and robustness of TOPSIS method in MRO studies.

The manufacturing sector has accepted TOPSIS methodology to discover the optimal settings of machine/process parameters from a finite number of alternatives for overall improvement in performance level[23]. Various fields of study like supply chain management, water resource management, human resource management, rural development, etc. have also adopted TOPSIS to resolve the complex issues. Supply chain management has benefitted tremendously because of the cost-effective production of products at the optimum setting of production parameters. TOPSIS based selection of best material for the specific applications would most likely result in an early payback of project investments. Material selection has a strong influence on product research, design, and development that ultimately impacts the competitiveness of products in the market. Improper selection of material may fail to fulfill customer requirements. Supplier selection problems also have used TOPSIS as it can select the best supplier quickly from the pool of suppliers with given criteria. Selection of site locations of factories based on optimization studies using TOPSIS could also add to supply chain efficiency. Modeling with TOPSIS can help in efficient operations by varying the input parameters in an optimum way to meet dynamic customer demands.

3.4 Implications of the study

This study will contribute to the enrichment of literature on the TOPSIS method. TOPSIS results can help in better planning and strategic decision making to implement the optimal and near-optimal solutions in a scientifically prioritized manner for optimum results in quick time. This study will guide the engineers, researchers, and supply chain managers on the application of this progressive MCDM technique for optimization problems in technical domains, and other applied fields. Material science and engineering will benefit immensely from the TOPSIS approach with its optimal results in quick time. The manufacturing industry can become more productive and efficient by using the optimal materials and optimal combination of input process parameters. Optimal set of machining parameters is very critical for highly productive manufacturing operations in terms of high-quality products, reduced machining costs, and maximum profitability. This study will give insights to supply chain managers on effective management of resources through optimization of performance parameters. The selection of optimum solutions can increase the productivity and competitiveness of supply chains with quality products/services at competitive costs. TOPSIS can be explored for application in other applied systems wherein multiple constraints pull the performance down when there are multiple alternatives to choose from.

4 Conclusions

- This study has focused on the usage of TOPSIS in the material science and engineering sector and found that the operation of machines at optimal settings of the input parameters had resulted in improvement of the preference values of the overall system.
- TOPSIS has been used in the metal processing and machining sector in more than 67% of articles to find the optimal settings of input variables of machining processes by optimizing multiple output responses for machining metals and non-metals.
- TOPSIS can be considered as the best MCDM method for the selection of optimum solutions for optimization of the overall efficiency of systems. Researchers have been showing increasing interest in using TOPSIS for MRO problems.
- TOPSIS continues to work adequately in the diverse fields of application like transportation sector, computing domain, environment and water resources management, supply chain management, etc.
- TOPSIS produces results faster than other MCDM techniques as it has the ability to compare and analyze the complete data simultaneously. It can produce results closer to the ideal solutions by using simple computational techniques with less time.
- TOPSIS has advantages like rationality, uncomplicatedness, clarity, and better computational efficiency. It can be used either solely or in combination with other MCDM techniques for better conclusive results by avoiding non-optimal decisions.
- TOPSIS is a reliable optimization tool for MRO problems. In many studies, the results of TOPSIS were found in conformity with the results of other MCDM techniques which indicates the credibility of the TOPSIS method.
- Optimal set of machining parameters is very critical for highly productive manufacturing operations in terms of high-quality products, reduced machining costs, and maximum profitability.
- There could be a surge in publications of articles on TOPSIS post Covid19 pandemic as many states and union territories in India with reputed educational institutions are yet to adopt TOPSIS in research and development in material science and engineering.
- TOPSIS can be used in advanced engineering applications like Chemical engineering, biotechnology, Additive Manufacturing, and also in supply chain management, where multiple constraints need to be optimized with the given alternatives.

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