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(Research Article)

Multi-criteria decision-making approach for selection of nano-additives in tribological applications using TOPSIS and SAW methods

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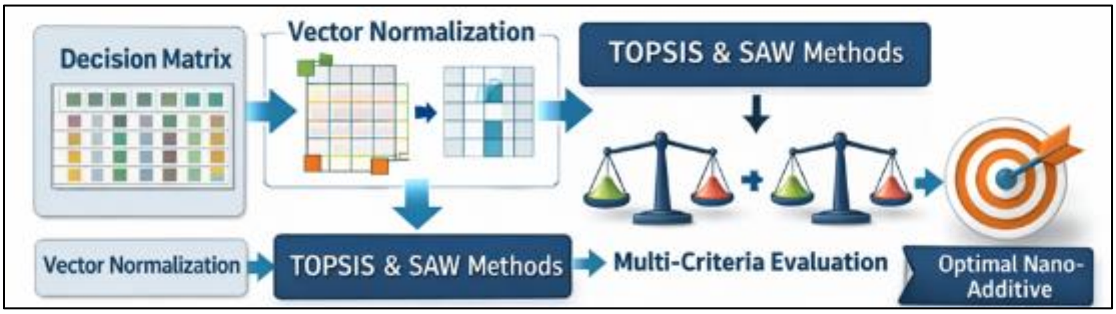
Abstract

The choice of appropriate nano additives for tribological purposes has many factors and requirements to be met. These include: lower friction; better wear properties; formation of protective tribofilms; good dispersibility in lubricant; and good thermal oxidation stability. In this paper, an MCDM (Multi-Criteria Decision Making) framework is presented for evaluating/ranking different types of nano additives used in the tribological field. Specifically, MoS_2, WS_2, MoO_3, TiO_2, Al_2O_3, SiO_2, and glycerol were evaluated. To select the best nano additive, a comparison was made with each other based on how close they came to the "ideal" solution. This comparison was done using the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

A decision matrix was prepared from published experimental data. Then, after normalizing each criterion and assigning weights to each one, the results were ranked. Finally, to validate the rankings obtained from the TOPSIS analysis, a second decision-making technique called SAW (Simple Additive Weighting) was applied. The rankings from both decision-making techniques were consistent and confirmed the effectiveness of the multi-criteria decision-making approach. From the TOPSIS analysis, it could be concluded that MoS_2 achieved the greatest value for closeness to the "ideal" solution which indicates that MoS_2 exhibited the most favorable behavior when considering all criteria. Additionally, it appears that MoO_3 and WS_2 will serve as possible candidates for use in future studies or as substitutes in certain applications where high temperatures and/or heavy loads exist.

Keywords: Nano-additives; Tribology; MADM; TOPSIS; SAW

Graphical Abstract



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1. Introduction

There has been an increasing demand for high-performance lubricating systems recently with the advancement in mechanically operating at extreme conditions (temperature, high loads, etc.). Typically conventional lubricant do not perform well in protecting against high friction, wear, and loss of energy. Nano additives have recently been recognized as a potential means of improving the tribological characteristics of conventional lubricants. Nano-additives that have shown improvement in tribological characteristics include molybdenum disulfide (MoS_2), tungsten disulfide (WS_2), molybdenum trioxide (MoO_3), titanium dioxide (TiO_2), aluminum oxide (Al_2O_3) and silicon dioxide (SiO_2). A number of factors influence the selection of the best nano additive; however there are also many conflicting factors such as dispersion stability, oxidation resistance, and thermal performance. As a result, there is a need for both qualitative and quantitative methodologies to systematically evaluate and compare all the possible options. Multi-criteria decision making (MCDM) approaches have become popular in solving similar problems. One common methodology used to solve multi-criteria decision making (MCDM) problems includes Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). TOPSIS is attractive because it uses a logical process of identifying the option that is closest to the ideal solution while being furthest from the worst solution. Another MCDM methodology commonly used is Simple Additive Weighting (SAW); the advantage of SAW over other methodologies is its simplicity and interpretability. This research develops a multi-criteria decision support system that evaluates and ranks nano-additives based on several key performance indicators related to tribology and thermals (friction coefficient reduction, wear coefficient reduction, tribofilm thickness, dispersion stability, oxidation temperature). This ranking was performed using the TOPSIS methodology, and validated using the SAW methodology.

2. Literature Review

The development of engineering systems to perform better than they do today is driven by the increasing number of new additives and materials being developed and applied. Those same new materials can enhance performance of a wide variety of engineering systems; and thermal management and energy related applications represent an important subset of those. It has long been recognized that the choice of the right materials will be essential to achieving both reliable and efficient operation. Recently there has been increased interest in applying nanomaterials and nanotechnology in various areas of engineering, specifically in thermal systems. As a result, many researchers are focusing their efforts on evaluating how nanomaterials and nanotechnology may provide improved thermal conductivity and overall thermal system performance. Examples of applications include the use of nanofluids as coolants for thermal management of batteries in hybrid/electric vehicle powertrains where it has been found that when advanced cooling techniques were used, there was significant improvement in temperature control and overall efficiency [1]; and the use of nanofluids as coolants which improved the convective heat transfer coefficient from a heated surface into the coolant, thereby improving cooling performance in high performance applications [2]-[3].. Research has also been performed to determine the energy usage during charging/discharging cycles and to optimize the performance of electric vehicles by demonstrating the need for material/thermal system level decision-making to maximize performance over a range of different operating conditions [4]-[5]. Furthermore, research has demonstrated that the thermal performance of a system utilizing diffusion absorption cooling with a refrigerant mixture such as tetrafluoroethane (R134a) and dimethylformamide (DMF), demonstrates that performance is heavily influenced by the amount of input energy and the properties of the working fluids. Studies conducted demonstrate the influence of thermophysical properties and operating conditions on the enhancement of heat transfer rates and therefore system performance. Consequently, these studies support the importance of advanced materials in thermal management applications. Moreover, studies have demonstrated that the selection of the correct materials for a particular application, including nano-additives, is critical to optimizing performance while minimizing degradation through prolonged exposure to operating conditions. Additionally, recent studies using decision making methods for material selection demonstrate the advantages of systematically analyzing large amounts of data. For example, studies involving weighted summation methodologies for material selection in biomedical and engineering applications demonstrate the importance of multi-criteria analysis in identifying the optimal material(s) necessary for meeting specific requirements [7]-[10]. Although progress has been made toward developing tools for material selection using decision making methodologies; however, most previous studies have focused on single domain optimizations, such as thermal performance or energy efficiency. However, there exists very little research regarding the simultaneous consideration of multiple tribological and thermal performance metrics for selecting nano-additives. This lack of consideration creates a need for applying Multi-Criteria Decision Making (MCDM) techniques for comprehensive evaluation and comparison of alternatives. Therefore, in this study, two MCDM methodologies, TOPSIS and SAW, are used to develop a systematic approach to select nano-additives based on multiple criteria, and consequently establish an objective method for determining the best nano-additive for a given tribological application.

3. Methodology

3.1. Implementation of TOPSIS

3.1.1. Step 1: Decision Matrix

Table 1 Decision Matrix

Nano-Additive	Friction Reduction (ΔCOF)	Wear Reduction	Tribofilm Thickness (nm)	Dispersion Stability (h)	Oxidation (°C)	Reference
MoS_2	65	95	85	72	275	[10]
Al_2O_3	28	70	20	70	200	[11]
SiO_2	20	48	12.5	80	180	[12]
Glycerol	12	18	2	100	150	[13]
WS_2	48	75	65	48	280	[14]
MoO_3	22	55	55	60	400	[15]
TiO_2	30	60	40	65	320	[16]

3.1.2. Step 2: Vector Normalization

$$r_{ij} = x_{ij} / \sqrt{\sum x_{ij}^2} \quad \text{.........(1)}$$

3.1.3. Step 3: Normalized Matrix (R)

Table 2 Normalized Matrix

Additive	C_1	C_2	C_3	C_4	C_5
MoS_2	0.659	0.584	0.632	0.375	0.378
Al_2O_3	0.284	0.430	0.149	0.365	0.275
SiO_2	0.203	0.295	0.093	0.417	0.247
Glycerol	0.122	0.111	0.015	0.522	0.206
WS_2	0.487	0.461	0.483	0.250	0.385
MoO_3	0.223	0.338	0.409	0.313	0.550
TiO_2	0.304	0.369	0.297	0.339	0.440

3.1.4. Step 4: Weighted Normalized Matrix (V)

Table 2 Weighted Normalized Matrix

Additive	C_1	C_2	C_3	C_4	C_5
MoS_2	0.099	0.088	0.126	0.038	0.151
Al_2O_3	0.043	0.065	0.030	0.037	0.110
SiO_2	0.030	0.044	0.019	0.042	0.099
Glycerol	0.018	0.017	0.003	0.052	0.082
WS_2	0.073	0.069	0.097	0.025	0.154
MoO_3	0.033	0.051	0.082	0.031	0.220
TiO_2	0.046	0.055	0.059	0.034	0.176

3.1.5. Step 5: Ideal Best (A^+) and Worst (A^-)

A^+ (Best values) = (0.099, 0.088, 0.126, 0.052, 0.220),

A^- (Worst values) = (0.018, 0.017, 0.003, 0.025, 0.082)

3.1.6. Step 6: Separation Measures

Distance from Ideal Best (S^+) and Worst (S^-)

Table 3 Separation measures

Additive	**S^+**	**S^-**
MoS_2	0.075	0.181
WS_2	0.095	0.156
MoO_3	0.093	0.159
TiO_2	0.104	0.140
Al_2O_3	0.130	0.103
SiO_2	0.146	0.092
Glycerol	0.170	0.068

3.1.7. Step 7: Closeness Coefficient (C_i)

$C_i=S^- / S^- + S^+$……….(2)

Table 4 Closeness Coefficient

Rank	**Additive**	**C_i**
1	MoS_2	0.707
2	MoO_3	0.631
3	WS_2	0.621
4	TiO_2	0.574
5	Al_2O_3	0.442
6	SiO_2	0.387
7	Glycerol	0.286

The TOPSIS analysis produced results identical to WASPAS and COPRAS, further validating the robustness of the decision-making framework. The consistency across three different MADM techniques confirms that MoS_2 is the most suitable nano-additive, primarily due to its superior friction reduction, wear resistance, and balanced thermal stability. MoO_3 consistently ranks second, driven by its excellent oxidation resistance and high-temperature performance. The close competition between MoO_3 and WS_2 highlights the trade-off between tribological efficiency and thermal durability.

3.2. Simple Additive Weighting (SAW) Method

The Simple Additive Weighting (SAW) method is highly suitable for this study due to its simplicity and transparency in decision-making. It is one of the most widely used techniques in engineering applications, making it easy to understand, implement, and justify in research studies related to material and nano-additive selection.

The method allows direct aggregation of weighted criteria, enabling straightforward comparison of alternatives without the need for complex distance measures or compromise calculations. This makes SAW particularly effective for evaluating nano-additives based on multiple performance parameters, ensuring clarity and reliability in the ranking process.

3.2.1. Step 1: Decision Matrix

Table 5 Decision Matrix for SAW

Additive	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
MoS_2	65	95	85	72	275
Al_2O_3	28	70	20	70	200
SiO_2	20	48	12.5	80	180
Glycerol	12	18	2	100	150
WS_2	48	75	65	48	280
MoO_3	22	55	55	60	400
TiO_2	30	60	40	65	320

3.2.2. Step 2: Normalization

Since all are benefit criteria, $r_{ij}=x_{ij} / \max. (x_j)$ ……….(2)

3.2.3. Step 3: Normalized Matrix

Table 6 Normalized Matrix

Additive	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**
MoS_2	1.000	1.000	1.000	0.72	0.688
Al_2O_3	0.431	0.737	0.235	0.70	0.500
SiO_2	0.308	0.505	0.147	0.80	0.450
Glycerol	0.185	0.189	0.024	1.00	0.375
WS_2	0.738	0.789	0.765	0.48	0.700
MoO_3	0.338	0.579	0.647	0.60	1.000
TiO_2	0.462	0.632	0.471	0.65	0.800

3.2.4. Step 4: Assign Weights

Weights:

$C_1 = 0.15$

$C_2 = 0.15$

$C_3 = 0.20$

$C_4 = 0.10$

$C_5 = 0.40$

3.2.5. Step 5: SAW Score Calculation

$$S_i=\sum (w_j . r_{ij}) \text{ ……….(3)}$$

3.2.6. Step 6: Final SAW Scores

Table 7 Final SAW Score

Rank	Additive	SAW Score
1	MoS_2	0.875
2	MoO_3	0.720
3	WS_2	0.704
4	TiO_2	0.675
5	Al_2O_3	0.543
6	SiO_2	0.495
7	Glycerol	0.441

4. Results and Discussion

The rankings of the additives using TOPSIS and SAW were generally consistent as well. All three additives have similar overall rankings. MoS2 was ranked first in both methods because of its superior ability to reduce friction, its good resistance to wear, and because it was able to achieve a balance among the different criteria. MoO3 ranked second primarily based on its significant oxidation resistance (which contributed greatly to its high temperature lubricant performance). WS2 was third, had good tribological behavior but less thermal stability than MoO3. TiO2 and Al2O3 each had average performances since they each had some positive characteristics. However, SiO2 and glycerol each had poor tribological properties, resulting in their low rankings. Since the rankings obtained with TOPSIS and SAW are so similar, this indicates that the structure of our decision support system has been established effectively, and the method used to determine weights is appropriate.

4.1. Comparative Analysis

In order to prove the feasibility and dependability of the proposed decision- making framework, an evaluation based on several multi-criteria decision-making (MCDM) approaches was undertaken. The considered MCDM techniques are TOPSIS, SAW, as well as those employed previously — WASPAS and COPRAS. All the investigated MCDM techniques produced identical ranks of alternatives. Specifically, MoS_2 remained in the first place while MoO_3 and WS_2 occupied second and third places respectively. As for the other materials under investigation, TiO_2, Al_2O_3, SiO_2, and glycerol, they retained their original ranks over all MCDM techniques. A uniformity in ranks of all alternatives provided via different MCDM techniques confirms that the evaluated process has a stable nature. Therefore, it can be concluded that the selected attributes and their corresponding weights do not affect the decision-making process; therefore, they have been correctly defined. Additionally, results of this study confirm its reliability and strong methodological validation. These results support applicability of the suggested methodology in real world engineering practice especially when selecting nanomaterials as additives in developing new generation tribosystems.

5. Conclusion

To create a holistic multi-criteria decision-making (MCDM) methodology to select and classify the most appropriate nano-additives for use in tribology by combining two separate methodologies; TOPSIS and SAW. These methodologies produced consistent rankings that placed MoS_2 as the best nano additive based upon it's ability to reduce friction and wear and maintain thermal stability. MoO_3 and WS_2 were ranked close behind as potential nano additives with particular advantages at high temperatures. The consistency across these different methodologies supports the validity and reliability of this methodology. It is demonstrated here that MCDM methodology provides an effective and systematic method for selecting materials for engineering applications. Further research could include the incorporation of other factors such as cost, environmental concerns and laboratory verification.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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