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# Effect of Normalization Techniques on MEMS Digital Micromirror Selection using MADM Methodology

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**Abstract: The main objective of this work is to evaluate the effect of different normalization techniques within multiple attribute decision making (MADM) methods. The application of the work is dedicated to MEMS digital micro-mirror selection for a given industrial application. To this end, the general scheme of the decision model is first presented, with close attention to the context of digital micro-mirror selection. Subsequently, TOPSIS is employed to rank the digital micro-mirror. Finally, by the introduction of different norms namely vector normalization, logarithmic normalization, linear max-min normalization, non-linear normalization and Lia & Hwang method are used in this work to the solution algorithm. A simple multiaxial strategy is also recommended from which better engineering decisions may be attained by obtaining different ranks for different micro-mirror alternatives.**

***Keywords: MADM, TOPSIS, Digital Micromirror, Normalization, Vector Normalization, Non-Linear Normalization Linear Max-Min Normalization, Logarithmic Normalization, Lia & Hwang Normalization.***

## I. INTRODUCTION

### A. MADM Methods

A considerable number of optimization methods have been employed in a broad class of MADM alternative selection applications. For MEMS technology compressing to the fingertips, we have more of the components to fit into small space. This has increased the consideration for only required essential constraint to be applied to the components and all the other parameters of lesser concern to be taken on skirts. This has given rise to production of MEMS devices, which are at first analysed using MADM technique to get the ideal parameters out of all the parameters that govern the working of the device to be optimized out of all the available alternatives. This has therefore drastically reduced the cost and production time of such devices. We, thus have taken study of MADM process on real-life case study of Micromirror to analyze the optimum geometry of the micromirror with TOPSIS technique.

### B. Literature

Most of the work in this field is limited to study of the techniques. We have thus considered various normalization techniques in TOPSIS [1] and have applied them on some of the real-life example to perform a case-study on various geometries available of the micromirrors [2, 3]. A detailed case-study is thus required to completely understand the implications from the use of MADM methods in manufacturing of MEMS Devices. To help address the issue of effective evaluation and justification of selection, various mathematical and systems modelling approaches have been proposed [4-7].

### C. Methodology

In case of using MADM in selection of optimum geometries for manufacturing, we first collect all the available geometries. We shortlist some of the geometries based on preliminary requirements of the device like shape, available space, application restriction, operating environments etc. Then the short-listed geometries are taken for MADM analysis, based on various attributes that the device possess. All the parameters that are considered have some level of relative importance. We call them weights of the parameters. These parameters are defined by the experts in the field. We check these parameters for

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consistency and perform some fine-tuning if required. Then the alternatives are taken for analysis by

TOPSIS method. Once the optimum geometry is selected, i.e. Structural, Dynamic and Fluid, is performed on the simulation software. Once the geometry is found acceptable, it is sent to the manufacturing units for quality and material acquiring related tasks and final fabrication. As all the testing is done on the models, it reduces testing time as this would require more time, if a prototype is to be made for all initial testing.

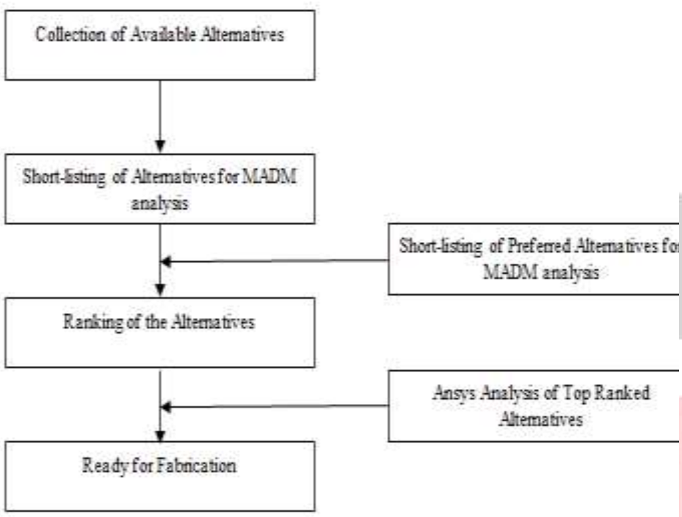


**Figure 1: Flowchart of methodology used in MADM process in MEMS Device Fabrication**

As discussed in fig. 1, process starts from selecting the sample space of the micromirrors. We collect data for the alternatives available and then tabulate them to form the data table. We, then provide the relative weights for the parameters taken into consideration. Once these parameters are found consistent in the AHP process, we proceed further to analyze the alternatives using TOPSIS method. It is this method that forms the base of this paper. We analysis the most preferred alternative is taken for further refinement and then for production. We have analysed the alternatives with TOPSIS process and various of its normalization techniques to check if they yield same, comparable or different results, when applied to same set of data.

## D. TOPSIS Technique

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is a method widely used in MADM processes to select alternatives that are nearer to our preferred solution. It is based on normalising of various parameters of the object under consideration and then to find the distance of the parameters from the most ideal and worst available alternatives. The process consists of following steps:

**Step 1**: Create a matrix comprising of m alternatives and n number of criteria, with each alternative and criteria intersect at point given as $x_{ij}$. We therefore, have a matrix $(x_{ij})_{mxn}$.

**Step 2**: The matrix $X_{mxn}$ is then normalized to form another matrix

R = using the normalization method,

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}}, i = 1, 2, \dots\dots, m \qquad (1)$$

**Step 3**: Evaluating the weighted normalized matrix.

$$t_{ij} = r_{ij} \cdot w_j, \quad i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n \qquad (2)$$

where,

$$w_j = W_j \Big/ \sum_{k=1}^{n} W_k, j = 1, 2, \dots, n \text{ so that } \sum_{i=1}^{n} w_i = 1, \text{ and } W_j$$

is the weight of the attributes given as $v_j$, j = 1,2, ….m

**Step 4**: Determine the least preferred alternative ($A_w$) and the most preferred alternative ($A_b$)

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$$A_w = \{\langle \max(t_{ij} \mid i = 1,2,\ldots,m) \mid j \in J_- \rangle, \langle \min(t_{ij} \mid i = 1,2,\ldots,m) \mid j \in J_+ \rangle\} \equiv \{t_{wj} \mid j = 1,2,\ldots,n\},$$
$$A_b = \{\langle \min(t_{ij} \mid i = 1,2,\ldots,m) \mid j \in J_- \rangle, \langle \max(t_{ij} \mid i = 1,2,\ldots,m) \mid j \in J_+ \rangle\} \equiv \{t_{bj} \mid j = 1,2,\ldots,n\}, \quad (3)$$

As,

$J_+ = \{j \in 1,2,3, \ldots n\}$ for the criteria having preferred impact, and

$J_- = \{j \in 1,2,3, \ldots n\}$ for the criteria having non-preferred impact

**Step 5**: Calculate $L^2$ – distance between an alternative I and the most unfavored condition $A_w$

$$d_{iw} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{wj})^2}, \quad i = 1,2,\ldots,m, \quad (4)$$

and distance between an alternative I and the most favored condition $A_b$

$$d_{ib} = \sqrt{\sum_{j=1}^{n} (t_{ij} - t_{bj})^2}, \quad i = 1,2,\ldots,m \quad (5)$$

where, $d_{iw}$ and $d_{ib}$ are $L^2$ – normal distances from the alternative I to the unfavored and the favored conditions, respectively.

## E. Normalization Methods in TOPSIS

There are various techniques for normalising of the parameters available. This is required as the parameters may be of myriad types that may not be compatible enough to be compared together. We thus normalize the parameters of all attributes before analysis. Various available techniques of normalization considered are:

a. Vector Normalization Technique:

for benefit criteria, $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ (6)

for cost criteria, $r_{ij} = 1 - \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$ (7)

b. Linear Max-Min Normalization Technique:

for benefit criteria, $r_{ij} = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}$ (8)

for cost criteria, $r_{ij} = \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}$ (9)

c. Logarithmic Normalization Technique:

for benefit criteria, $r_{ij} = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}$ (10)

for cost criteria, $r_{ij} = \frac{x_j^+ - x_{ij}}{x_j^+ - x_j^-}$ (11)

d. Non-Linear Normalization Technique:

for benefit criteria, $r_{ij} = (\frac{x_{ij}}{x_j^+})^2$ (12)

for cost criteria, $r_{ij} = (\frac{x_j^-}{x_{ij}})^2$ (13)

e. Lia & Hwang Normalization Technique:

for benefit criteria, $r_{ij} = \frac{x_{ij}}{x_j^+ - x_j^-}$ (14)

(15)

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for cost criteria, $r_{ij} = \frac{x_{ij}}{x_j^- - x_j^+}$

## II. CASE STUDY OF MEMS DIGITAL MICROMIRROR

A variety of concepts regarding the use of micromirror technology in display devices have been put forward. In general, the displays using micromirrors need a light source and a lens. We have collected data of 4 design alternatives for the micro-mirrors as available from 2000 onwards.

In the alternatives available, sources of different designs are,

M1 – DuraScan mirror developed for low-speed beam scanning application [2]

M2 – Digital-8 mirror for optical telecommunication applications [2]

M3 – Micromirror for an optical scanner in a laser scanning microscope [3]

M4 – an electrostatically actuated bi-axial micromirror [4]

We perform our analysis on data table 2.1 to select the most preferred geometry of the micro-beam using TOPSIS Normalization Methods. The parameters taken into consideration for analysis are Mirror Surface Area represented as X1 (unit: $\mu m^2$), Resonant Frequency represented as X2 (unit: Hz), Max Allowable Rotation Angle represented as X3 (unit: Degrees), Actuation Voltage represented as X4 (unit: Volts), Curving Radius of the Surface represented as X5 (unit: cm), Reflectivity of the upper Surface represented as X6 (unit: %), tolerance of Rotation Angle represented as X7 (unit: %). Other parameters are assumed to be constants for simplicity.

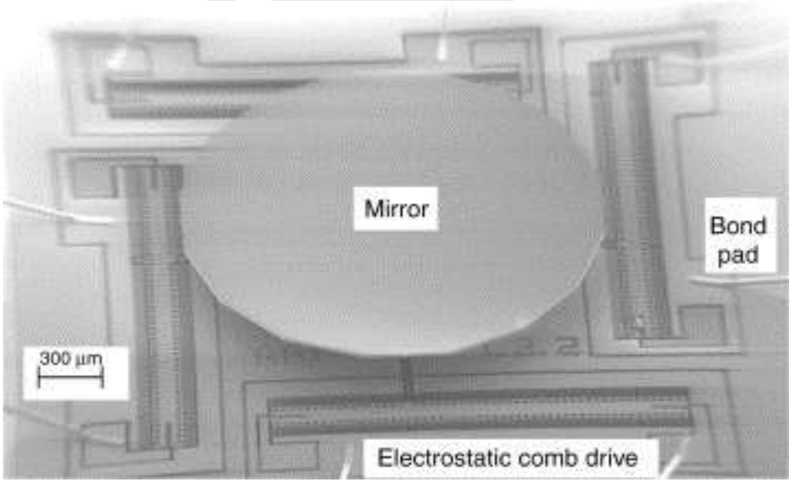


**Figure 2: SEM image of multi-axes scanning mirror; gimbal-less tip-tilt structure. (Source: Mirrocle Technologies, Inc., 2009) [5]**

**Table 1. Data Table for available geometries for Micro-mirror**

| Alternatives | X1 | X2 | X3 | X4 | X5 | X6 | X7 |
|---|---|---|---|---|---|---|---|
| | Mirror Area | Resonant Frequency | Max Rotation Angle | Actuation Voltage | Radius of Curvature | Surface Reflectivity | Rotation Angle Tolerance |
| | square micro-meter | Hz | Degrees | Volts | cm | percentage | percentage |
| M1 | 9000000 | 50 | 12 | 330 | 800 | 96 | 0.08 |
| M2 | 2250000 | 318 | 1.8 | 11 | 150 | 96 | 0.01 |
| M3 | 12600000 | 4100 | 16 | 200 | 244 | 85 | 0.1 |
| M4 | 3150000 | 500 | 2 | 200 | 200 | 95 | 0.05 |

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### A. Vector Normalization Technique

For the first scenario, we use the normalization formulae for Vector Normalization from equation 6 for benefit criteria and equation 7 for cost criteria. we use Results are as recorded in table 2.

**Table 2: Normalized Matrix using Vector Normalization for MEMS Digital Micro-Mirror**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.563883874 | 0.012068839 | 0.594642618 | 0.240970052 | 0.916436214 | 0.51548872 | 0.580381 |
| **M2** | 0.140970969 | 0.076757819 | 0.089196393 | 0.974699002 | 0.17183179 | 0.51548872 | 0.072547625 |
| **M3** | 0.789437424 | 0.989644831 | 0.792856824 | 0.53998185 | 0.279513045 | 0.456422304 | 0.72547625 |
| **M4** | 0.197359356 | 0.120688394 | 0.099107103 | 0.53998185 | 0.229109054 | 0.510119045 | 0.362738125 |

This change in Normalized matrix further changes the Weighted normalized matrix, distance of the alternative from ideal and most undesirable alternatives. The results are as recorded in table 3 for weighed matrix and table 4 for distance, Performance index and rank.

**Table 3: Weighted Normalized Matrix for Vector Normalization of MEMS Digital Micro-Mirror Alternatives**

| Alternative | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.080353452 | 0.001860967 | 0.071003302 | 0.035099457 | 0.119355736 | 0.073177232 | 0.096368783 |
| **M2** | 0.020088363 | 0.011835749 | 0.010650495 | 0.141973682 | 0.022379201 | 0.073177232 | 0.012046098 |
| **M3** | 0.112494833 | 0.152599274 | 0.094671069 | 0.078653216 | 0.0364035 | 0.064792341 | 0.120460978 |
| **M4** | 0.028123708 | 0.018609668 | 0.011833884 | 0.078653216 | 0.029838934 | 0.072414969 | 0.060230489 |

**Table 4: Distances, Performance Index and Ranks for MEMS Digital Micro-mirror Alternatives by Vector Normalization Method**

| si+ | si- | Pi | rank |
|---|---|---|---|
| 0.190572303 | 0.154464922 | 0.447676108 | 2 |
| 0.237846626 | 0.107665699 | 0.311611746 | 3 |
| 0.104694132 | 0.228402818 | 0.685694714 | 1 |
| 0.218139251 | 0.068402513 | 0.238717428 | 4 |

### B. Linear Max – Min Normalization Technique

We use the normalization formulae for Linear Max – Min Normalization from equation 8 for benefit criteria and equation 9 for cost criteria. we use Results are as recorded in table 5 below.

**Table 5: Normalized Matrix using Linear Max-Min Normalization for MEMS Digital Micro-Mirror**

| Alternative | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.652173913 | 0 | 0.718309859 | 0 | 1 | 1 | 0.777777778 |
| **M2** | 0 | 0.06617284 | 0 | 1 | 0 | 1 | 0 |
| **M3** | 1 | 1 | 1 | 0.407523511 | 0.144615385 | 0 | 1 |
| **M4** | 0.086956522 | 0.111111111 | 0.014084507 | 0.407523511 | 0.076923077 | 0.909090909 | 0.444444444 |

This change in Normalized matrix further changes the Weighted normalized matrix, distance of the alternative from ideal and most undesirable alternatives. The results are as recorded in table 6 for weighed matrix and table 7 for distance, Performance index and rank.


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**Table 6: Weighted Normalized Matrix for Linear Max-Min Normalization of MEMS Digital Micro-Mirror Alternatives**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.092934783 | 0 | 0.085769789 | 0 | 0.130239 | 0.141957 | 0.129145333 |
| **M2** | 0 | 0.010203587 | 0 | 0.145659 | 0 | 0.141957 | 0 |
| **M3** | 0.1425 | 0.154196 | 0.119405 | 0.059359467 | 0.018834563 | 0 | 0.166044 |
| **M4** | 0.012391304 | 0.017132889 | 0.001681761 | 0.059359467 | 0.010018385 | 0.129051818 | 0.073797333 |

**Table 7: Distances, Performance Index and Ranks for MEMS Digital Micro-mirror Alternatives by Linear Max - Min Normalization Method**

| si+ | si- | Pi | rank |
|---|---|---|---|
| 0.223478188 | 0.264170086 | 0.54172259 | 2 |
| 0.315959532 | 0.203647851 | 0.3919264 | 3 |
| 0.200025868 | 0.299648306 | 0.5996874 | 1 |
| 0.283107625 | 0.161784552 | 0.363648903 | 4 |

### C. Logarithmic Normalization Technique

We use the normalization formulae for Logarithmic Normalization from equation 10 for benefit criteria and equation 11 for cost criteria. we use Results are as recorded in table 8 below.

**Table 8: Normalized Matrix using Logarithmic Normalization for MEMS Digital Micro-Mirror**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.258472963 | 0.161604262 | 0.380046425 | 0.230477651 | 0.297216273 | 0.251822988 | 0.203209004 |
| **M2** | 0.236095799 | 0.238028268 | 0.089897228 | 0.290803033 | 0.222786664 | 0.251822988 | 0.370511713 |
| **M3** | 0.263904201 | 0.343644247 | 0.424045077 | 0.239359658 | 0.24441926 | 0.245108757 | 0.185255857 |
| **M4** | 0.241527037 | 0.256723223 | 0.106011269 | 0.239359658 | 0.235577803 | 0.251245268 | 0.241023426 |

This change in Normalized matrix further changes the Weighted normalized matrix, distance of the alternative from ideal and most undesirable alternatives. The results are as recorded in table 9 for weighed matrix and table 10 for distance, Performance index and rank.

**Table 9: Weighted Normalized Matrix for Logarithmic Normalization of MEMS Digital Micro-Mirror Alternatives**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.036832397 | 0.024918731 | 0.045379443 | 0.033571144 | 0.03870915 | 0.035748036 | 0.033741636 |
| **M2** | 0.033643651 | 0.036703007 | 0.010734179 | 0.042358079 | 0.029015512 | 0.035748036 | 0.061521247 |
| **M3** | 0.037606349 | 0.052988568 | 0.050633102 | 0.034864888 | 0.03183292 | 0.034794904 | 0.030760623 |
| **M4** | 0.034417603 | 0.039585694 | 0.012658276 | 0.034864888 | 0.030681417 | 0.035666024 | 0.040020494 |

**Table 10: Distances, Performance Index and Ranks for MEMS Digital Micro-mirror Alternatives by Logarithmic Normalization Method**

| si+ | si- | Pi | rank |
|---|---|---|---|
| 0.040804813 | 0.036252227 | 0.470459641 | 2 |
| 0.044348768 | 0.034105774 | 0.434720195 | 3 |
| 0.032412264 | 0.049042374 | 0.602082032 | 1 |
| 0.047061387 | 0.017617435 | 0.272383367 | 4 |

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### D. Non – Linear Normalization Technique

We use the normalization formulae for Non - Linear Normalization from equation 12 for benefit criteria and equation 13 for cost criteria. we use Results are as recorded in table 11 below.

**Table 11: Normalized Matrix using Non-Linear Normalization for MEMS Digital Micro-Mirror**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.510204082 | 0.000148721 | 0.5625 | 0.001111111 | 1 | 1 | 0.64 |
| **M2** | 0.031887755 | 0.006015705 | 0.01265625 | 1 | 0.03515625 | 1 | 0.01 |
| **M3** | 1 | 1 | 1 | 0.003025 | 0.093025 | 0.783962674 | 1 |
| **M4** | 0.0625 | 0.0148721 | 0.015625 | 0.003025 | 0.0625 | 0.979275174 | 0.25 |

This change in Normalized matrix further changes the Weighted normalized matrix, distance of the alternative from ideal and most undesirable alternatives. The results are as recorded in table 12 for weighed matrix and table 13 for distance, Performance index and rank.

**Table 12: Weighted Normalized Matrix for Non-Linear Normalization of MEMS Digital Micro-Mirror Alternatives**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.072704082 | 2.29322E-05 | 0.067165313 | 0.000161843 | 0.130239 | 0.141957 | 0.10626816 |
| **M2** | 0.004544005 | 0.000927598 | 0.00151122 | 0.145659 | 0.004578715 | 0.141957 | 0.00166044 |
| **M3** | 0.1425 | 0.154196 | 0.119405 | 0.000440618 | 0.012115483 | 0.111288989 | 0.166044 |
| **M4** | 0.00890625 | 0.002293218 | 0.001865703 | 0.000440618 | 0.008139938 | 0.139014966 | 0.041511 |

**Table 13: Distances, Performance Index and Ranks for MEMS Digital Micro-mirror Alternatives by Non-Linear Normalization Method**

| si+ | si- | Pi | rank |
|---|---|---|---|
| 0.23688 | 0.19139 | 0.44689 | 2 |
| 0.315015 | 0.148697 | 0.320667 | 3 |
| 0.189689 | 0.289446 | 0.604101 | 1 |
| 0.325962 | 0.048927 | 0.130511 | 4 |

### E. Lia & Hwang Normalization Technique

We use the normalization formulae for Lia & Hwang Normalization from equation 14 for benefit criteria and equation 15 for cost criteria. we use Results are as recorded in table 14 below.

**Table 14: Normalized Matrix using Lia & Hwang Normalization for MEMS Digital Micro-Mirror**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.869565217 | 0.012345679 | 0.845070423 | -1.034482759 | 1.230769231 | 8.727272727 | 0.888888889 |
| **M2** | 0.217391304 | 0.078518519 | 0.126760563 | -0.034482759 | 0.230769231 | 8.727272727 | 0.111111111 |
| **M3** | 1.217391304 | 1.012345679 | 1.126760563 | -0.626959248 | 0.375384615 | 7.727272727 | 1.111111111 |
| **M4** | 0.304347826 | 0.12345679 | 0.14084507 | -0.626959248 | 0.307692308 | 8.636363636 | 0.555555556 |

This change in Normalized matrix further changes the Weighted normalized matrix, distance of the alternative from ideal and most undesirable alternatives. The results are as recorded in table 15 for weighed matrix and table 16 for distance, Performance index and rank.

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**Table 15: Weighted Normalized Matrix for Lia & Hwang Normalization of MEMS Digital Micro-Mirror Alternatives**

| Alternatives | X1 (area) | X2 (frequency) | X3 (rot angle) | X4 (voltage) | X5 (radius) | X6 (reflectivity) | X7 (angle tolerance) |
|---|---|---|---|---|---|---|---|
| **M1** | 0.123913043 | 0.001903654 | 0.100905634 | -0.150681724 | 0.160294154 | 1.238897455 | 0.147594667 |
| **M2** | 0.030978261 | 0.012107241 | 0.015135845 | -0.005022724 | 0.030055154 | 1.238897455 | 0.018449333 |
| **M3** | 0.173478261 | 0.156099654 | 0.134540845 | -0.091322257 | 0.048889717 | 1.096940455 | 0.184493333 |
| **M4** | 0.043369565 | 0.019036543 | 0.016817606 | -0.091322257 | 0.040073538 | 1.225992273 | 0.092246667 |

**Table 16: Distances, Performance Index and Ranks for MEMS Digital Micro-mirror Alternatives by Lia & Hwang Normalization Method**

| si+ | si- | Pi | rank |
|---|---|---|---|
| 0.2234782 | 0.2641701 | 0.5417226 | 2 |
| 0.3159595 | 0.2036479 | 0.3919264 | 3 |
| 0.2000259 | 0.2996483 | 0.5996874 | 1 |
| 0.2831076 | 0.1617846 | 0.3636489 | 4 |

## III. RESULTS AND CONCLUSIONS

As given in the figure 1, we perform MADM analysis and moving forth from the data table 1, we apply vector normalization in table 2, weighted normalized matrix in table 3 and then, we get the distance of the worst and the most preferred geometry, performance index and ranks in table 4 using equations as given in equation 6 and equation 7. Table 5 comprises of normalized matrix for Linear Max-Min technique which is followed by weighted normalized matrix in table 6 and distances, performance index and ranks of the alternatives in table 7. Table 8 is formed of the normalized values of alternatives from the Logarithmic Normalization technique. Table 9 is the weighted normalized matrix for the method , while table 10 contains the distances of the alternatives from ideal solution, their performance index and the ranks of the alternatives. Table 11, table 12 and table 13 contain respectively the normalized matrix, weighted normalized matrix and distances of the alternatives, performance index and ranks respectively for Non-Linear Normalization technique. Similar data of normalization, weighted normalization and performance index, distances and ranks are tabulated in table 14, table 15 and table 16 respectively.

Thus, we conclude the results and compare the ranks from all the normalization techniques for MEMS Digital Micro-mirror in the table 17 and the graph 1.

**Table 17: Comparison of Ranks for Digital Micro-mirror Alternatives based on various Normalization techniques**

| Alternatives | Ranks | | | | |
|---|---|---|---|---|---|
| | Vector Normalization | Linear Max Min Normalization | Logarithmic Normalization | Non-Linear | Lia & Hwang |
| M1 | 2 | 2 | 2 | 2 | 2 |
| M2 | 3 | 3 | 3 | 3 | 3 |
| M3 | 1 | 1 | 1 | 1 | 1 |
| M4 | 4 | 4 | 4 | 4 | 4 |

As seen in the table 17, all the normalization methods yield the same result of rank for all the alternatives in the analysis. Geometry M3 is the most preferred geometry with least actuation voltage. This is followed by M1. Third rank is provided to Mirror alternative M3, while geometry M4 is the last one. Even when having actuation voltage same as M1, it is most unfavourable as it has other parameters that are least preferred namely least rotation tolerance and max allowable rotation

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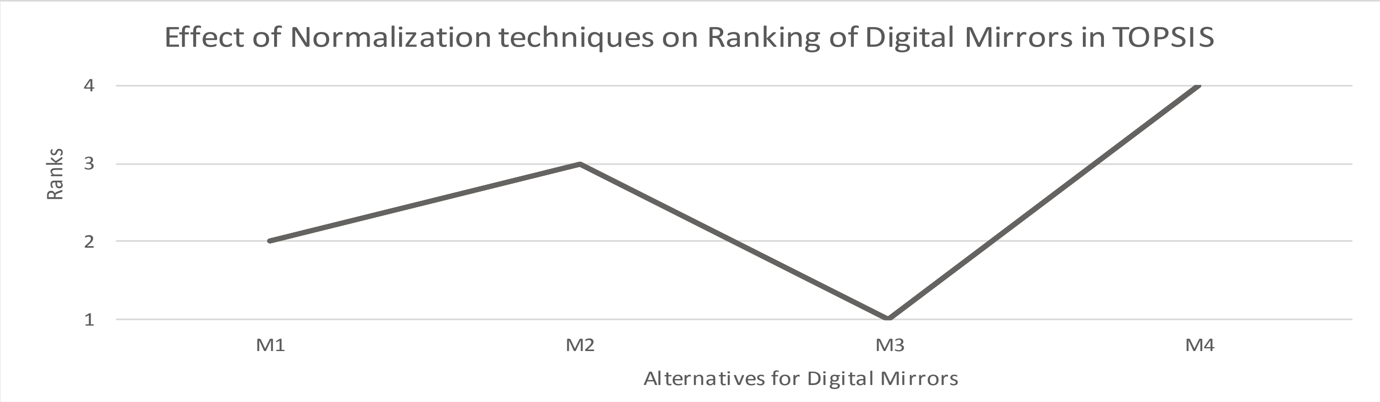
angle, Therefore, we may infer our analysis to be correct and consistent. Graph 1 below shows the curves for all the techniques to be overlapping as all the ranks from all the methods are same. This emphasises the findings of the analysis to be correct.




**Graph 1: Effect of Normalization techniques on the ranks of Alternatives for Digital Micro-mirror**

## IV. Conclusion

For the set of data considered in this paper, we conclude that the above-mentioned normalization techniques namely Vector Normalization, Linear Max-Min Normalization, Logarithmic Normalization, Non-Linear Normalization and Lia & Hwang Normalization techniques yield same ranks for digital micromirror with properties mirror surface area, resonant frequency, max allowable rotation angle, actuation voltage, curving radius of the Surface, reflectivity of the upper surface, tolerance of rotation angle taken into consideration. This work is limited to the MADM analysis of a few alternatives of the digital micromirror using TOPSIS technique only with various normalization methods. For the fabrication of MEMS devices, further analysis and refining is required on simulation software that is beyond the scope of this work. TOPSIS technique is not limited to just the methods of normalization and distance calculations mentioned in this work. More of the methods, can thus be undertaken for simulation and case-study as future scope. There are many more methods of MADM analysis that are not considered in this work, most widely used being VIKOR. The same analysis may be carried out in Fuzzy environment as well to get much more dependable alternatives ranking in fuzzy environment. Much more alternatives may also be considered in MADM analysis for micromirror to bring forth more possible combinations of characteristic properties of the devices and their sensitivity analysis may be carried out.

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