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Research Article

M-Polynomials and Degree-Based Topological Indices of Mycielskian of Paths and Cycles

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Abstract. For a graph G, the M-polynomial is defined as $M(G;x,y) = \sum_{\delta \le \alpha \le \beta \le \Delta} m_{\alpha\beta}(G)x^{\alpha}y^{\beta}$, where $m_{\alpha\beta}(\alpha,\beta \ge 1)$, is the number of edges ab of G such that $\deg_G(a) = \alpha$ and $\deg_G(b) = \beta$, and δ is the minimum degree and Δ is the maximum degree of G. The physiochemical properties of chemical graphs are found by topological indices, in particular, the degree-based topological indices, which can be determined from an algebraic formula called M-polynomial. We compute the closest forms of M-polynomial for Mycielskian of paths and cycles. Further, we plot the 3-D graphical representation of M-polynomial. Finally, we derive some degree-based topological indices with the help of M-polynomial.

Keywords. Topological indices, M-polynomial, Mycielskian of a graph, Path, Cycle

Mathematics Subject Classification (2020). 05C07, 05C31

1. Introduction

For all terms and definitions we refer to Harary [5]. Let the vertex set of a simple connected graph G be $V(G)$ and let $E(G)$ be its edge set, and let n and m, respectively, denotes the order and size of G. A *chemical graph* is a labeled graph where the atoms correspond to the vertices and the chemical bonds of the compound corresponds to the edges. A numerical quantity which is used to analyse both the physical and chemical properties of compounds is termed as a topological index. A topological index is also called a *graph invariant*. In general, the physiochemical properties and boiling activities of a chemical graph are investigated using topological indices.

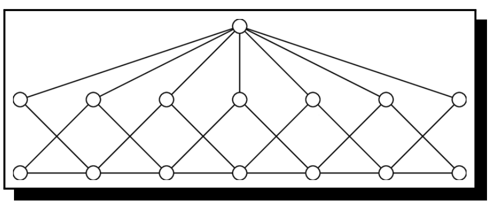
H. Weiner [13] initiated the study of topological indices in the year 1947. The concept of Weiner index was first introduced by Weiner [13] mainly to know the correspondence of the attributes of molecules in a compound along with structural property. Hosoya [6] explained the Weiner index using the concept of distance between vertices in a graph in the year 1972. For more work done on topological indices, we refer the reader to Brückler *et al*. [1], Das *et al*. [2], and Fath-Tabar *et al*. [4].

There are many algebraic polynomials available in the literature. One such a polynomial is Hosoya polynomial, which is used to determine the distance-based topological indices. An important class of algebraic polynomial introduced by Deutsch and Klavžar [3] called M-polynomial is used to determine the closest form of various topological indices based on degree. For more work done on finding topological indices using M-polynomial, we refer the reader to Khalaf *et al*. [7], Kwun *et al*. [8], Munir *et al*. [10,11], and Swamy *et al*. [12].

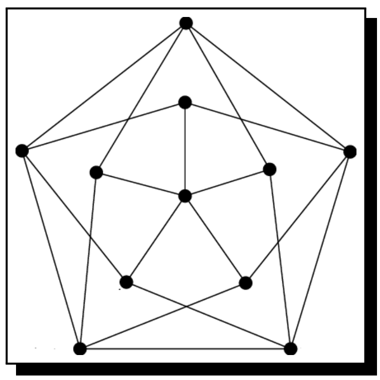
The notion of Mycielskian graph of a given graph G by Lin *et al*. [9] is defined as follows:

Definition 1.1. For a graph G, the *Mycielskian* of G, denoted by $\mu(G)$, is the graph with $V(\mu(G)) = X \cup Y \cup \{b\}$ such that $x_i x_j \in E(\mu(G)) \iff x_i x_j \in E(G)$, with $x_i y_j \in E(\mu(G)) \iff x_i x_j \in E(G)$, with $y_i b \in E(\mu(G))$, $i \in [1,n]$; and no more edges in $E(\mu(G))$, where $x_i \in V(G)$ and $y_i \in Y$.

Figure 1(a) and Figure 1(b) shows an example of Mycielskian of a path P_7 and a cycle C_5, respectively.



(a) $\mu(P_7)$



(b) $\mu(C_5)$

Figure 1

Inspired by the studies as mentioned above, we aim to calculate the M-polynomial and degree-based topological indices of $\mu(P_7)$ and $\mu(C_5)$.

2. Methodology

We procedure that we follow is as follows:

Step 1: Initially, $E(\mu(P_7))$ and $E(\mu(C_5))$ are divided into separate classes depends on the end vertices degree.

Step 2: With the help of this edge division (*Step* 1), we compute the M-polynomial of Mycielskian of paths and cycles.

Step 3: The degree-based topological indices as listed in Section 3 are computed using M-polynomial.

Step 4: Using MATLAB, the 3-D graph corresponding to M-polynomials are plotted.

3. Preliminaries

Definition 3.1. The M-polynomial of a graph G is defined as $M(G;x,y) = \sum_{\delta \le \alpha \le \beta \le \Delta} m_{\alpha\beta}(G) x^\alpha y^\beta$, where $m_{\alpha\beta}(\alpha,\beta \ge 1)$, is the number of edges ab of G such that $\deg_G(a) = \alpha$ and $\deg_G(b) = \beta$, and δ is the minimum degree and Δ is the maximum degree of G.

Using M-polynomial, degree-based topological indices are derived with the help of operations as mentioned in following table. Let $M(G;x,y) = f(x,y)$. Then using M-polynomial, degree-based topological indices are derived with the help of operations as mentioned below.

Notation	*Topological Index*	*Derivation from* $M(G;x,y)$
$M_1(G)$	First Zagreb index	$(D_x + D_y)(f(x,y))\|_{x=1;y=1}$
$M_2(G)$	Second Zagreb index	$(D_x D_y)(f(x,y))\|_{x=1;y=1}$
${}^mM_2(G)$	Second modified Zagreb index	$(S_x S_y)(f(x,y)))\|_{x=1;y=1}$
$SSD(G)$	Symmetric division index	$(D_x S_y + D_y S_x)(f(x,y))\|_{x=1;y=1}$
$H(G)$	Harmonic index	$2S_x J(f(x,y))\|_{x=1}$
$I(G)$	Inverse sum index	$S_x J D_x D_y(f(x,y)))\|_{x=1}$

Here, $D_x(f(x,y)) = x\left(\frac{\partial f(x,y)}{\partial x}\right)$, $D_y(f(x,y)) = y\left(\frac{\partial f(x,y)}{\partial y}\right)$, $S_x(f(x,y)) = \int_0^x \left(\frac{f(t,y)}{t}\right) dt$, $S_y(f(x,y)) = \int_0^y \left(\frac{f(x,t)}{t}\right) dt$, and $J[f(x,y)] = f(x,x)$ are the operators.

4. M-polynomial of Mycielskian of Paths

In this section, we find the M-polynomial of Mycielskian of paths.

Theorem 4.1. *Let P_n be a path of order $n \ge 2$. Then $M(\mu(G))$ is*

$$M(\mu(G);x,y) = 2x^2y^3 + 4x^2y^4 + 2x^2y^n + 2(n-3)x^3y^4 + (n-2)x^3y^n + (n-3)x^4y^4.$$

Proof. Let $G = P_n$ be a path of order n, $n \ge 2$. It is easy to observe from Figure 1(a) that

$$|V(\mu(G))| = 2n+1 \quad \text{and} \quad |E(\mu(G))| = 4n-3.$$

Since each vertex of G is of degree either 2 or 3 or 4 or n, the partitions of $V(\mu(G))$ be:

$$V_1(\mu(G)) := \{v \in V(\mu(G)) : \deg_{\mu(G)}(v) = 2\},$$

$V_2(\mu(G)) := \{v \in V(\mu(G)) : \deg_{\mu(G)}(v) = 3\}$,
$V_3(\mu(G)) := \{v \in V(\mu(G)) : \deg_{\mu(G)}(v) = 4\}$,
$V_4(\mu(G)) := \{v \in V(\mu(G)) : \deg_{\mu(G)}(v) = n\}$.

Clearly,

$$|V_1(\mu(G))| = 4, \quad |V_2(\mu(G))| = n-2, \quad |V_3(\mu(G))| = n-2, \quad |V_4(\mu(G))| = 1.$$

Furthermore, the partitions of edge set $E(\mu(G))$ are:

$E_1(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 2, \deg_{\mu(G)}(b) = 3\}$,
$E_2(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 2, \deg_{\mu(G)}(b) = 4\}$,
$E_3(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 2, \deg_{\mu(G)}(b) = n\}$,
$E_4(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 3, \deg_{\mu(G)}(b) = 4\}$,
$E_5(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 3, \deg_{\mu(G)}(b) = n\}$,
$E_6(\mu(G)) := \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 4, \deg_{\mu(G)}(b) = 4\}$.

Clearly,

$$|E_1(\mu(G))| = 2, \quad |E_2(\mu(G))| = 4, \quad |E_3(\mu(G))| = 2, \quad |E_4(\mu(G))| = 2(n-3),$$
$$|E_5(\mu(G))| = n-2, \quad |E_6(\mu(G))| = n-3.$$

Therefore,

$$\begin{aligned} M(G;x,y) &= \sum_{\delta \le \alpha \le \beta \le \Delta} m_{\alpha\beta}(\mu(G)) x^\alpha y^\beta \\ &= m_{23}(\mu(G))x^2y^3 + m_{24}(\mu(G))x^2y^4 + m_{2n}(\mu(G))x^2y^n + m_{34}(\mu(G))x^3y^4 \\ &\quad + m_{3n}(\mu(G))x^3y^n + m_{44}(\mu(G))x^4y^4 \\ &= 2x^2y^3 + 4x^2y^4 + 2x^2y^n + 2(n-3)x^3y^4 + (n-2)x^3y^n + (n-3)x^4y^4. \end{aligned}$$ □

For Mycielskian of paths, degree-based topological indices are computed using this M-polynomial in the next theorem.

Theorem 4.2. *Let $G = P_n$ be a path of order $n \ge 2$. Then,*

$$M_1(\mu(G)) = n^2 + 25n - 34,$$
$$M_2(\mu(G)) = 3n^2 + 38n - 76,$$
$${}^mM_2(\mu(G)) = \frac{11n^2 + 23n + 16}{48n},$$
$$SSD(\mu(G)) = \frac{2n^3 + 39n^2 - 7n - 12}{6n},$$
$$H(\mu(G)) = \frac{345n^3 + 2426n^2 + 3055n + 846}{420n^2 + 2100n + 2520},$$
$$I(\mu(G)) = \frac{885n^3 + 2372n^2 - 1070n - 5388}{105n^2 + 525n + 630}.$$

Proof. From Theorem 4.1, we have

$$M(\mu(G);x,y) = 2x^2y^3 + 4x^2y^4 + 2x^2y^n + 2(n-3)x^3y^4 + (n-2)x^3y^n + (n-3)x^4y^4.$$

Then, we have

$$D_x(f(x,y)) = 3(n-2)x^3y^n + 4x^2y^n + 4(n-3)x^4y^4 + 6(n-3)x^3y^4 + 8x^2y^4 + 4x^2y^3,$$

$$D_y(f(x,y)) = n(n-2)x^3y^n + 2nx^2y^n + 4(n-3)x^4y^4 + 8(n-3)x^3y^4 + 16x^2y^4 + 6x^2y^3,$$

$$(D_yD_x)(f(x,y)) = 3n(n-2)x^3y^n + 4nx^2y^n + 16(n-3)x^4y^4 + 24(n-3)x^3y^4 + 32x^2y^4 + 12x^2y^3,$$

$$S_x(f(x,y)) = \frac{((4n-8)x^3+12x^2)y^n + ((3n-9)x^4+(8n-24)x^3+24x^2)y^4 + 12x^2y^3}{12},$$

$$S_y(f(x,y)) = \frac{((12n-24)x^3+24x^2)y^n + ((3n^2-9n)x^4+(6n^2-18n)x^3+12nx^2)y^4 + 8nx^2y^3}{12n},$$

$$S_xS_y(f(x,y)) = \frac{((16n-32)x^3+48x^2)y^n + ((3n^2-9n)x^4+(8n^2-24n)x^3+24nx^2)y^4 + 16nx^2y^3}{48n},$$

$$S_yD_x(f(x,y)) = \frac{x(((18n-36)x^2+24x)y^n + ((6n^2-18n)x^3+(9n^2-27n)x^2+12nx)y^4 + 8nxy^3)}{6n},$$

$$S_xD_y(f(x,y)) = \frac{((n^2-2n)x^3+3nx^2)y^n + ((3n-9)x^4+(8n-24)x^3+24x^2)y^4 + 9x^2y^3}{3},$$

$$\begin{aligned}2S_xJ(f(x,y)) &= \frac{2(105n^3+210n^2-945n-1890)x^8 + 2(240n^3+480n^2-2160n-4320)x^7}{840n^2+4200n+5040}\\ &\quad + \frac{2(560n^2+2800n+3360)x^6 + 2(336n^2+1680n+2016)x^5}{840n^2+4200n+5040}\\ &\quad + \frac{2x^{n+3}(840n^2-3360) + 2x^{n+2}(1680n+5040)}{840n^2+4200n+5040},\end{aligned}$$

$$\begin{aligned}S_xJD_xD_y(f(x,y)) &= \frac{(210n^3+420n^2-1890n-3780)x^8 + (360n^3+720n^2-3240n-6480)x^7}{105n^2+525n+630}\\ &\quad + \frac{(560n^2+2800n+3360)x^6 + (252n^2+1260n+1512)x^5}{105n^2+525n+630}\\ &\quad + \frac{x^{n+3}(315n^3-1260n) + x^{n+2}(420n^2+1260n)}{105n^2+525n+630}.\end{aligned}$$

Now, we have the following:

(i) $M_1(\mu(G)) = (D_x(f(x,y) + D_y(f(x,y))|_{x=1;y=1} = n^2 + 25n - 34$,

(ii) $M_2(\mu(G)) = (D_x(f(x,y))(D_y(f(x,y))|_{x=1;y=1} = 3n^2 + 38n - 76$,

(iii) ${}^mM_2(\mu(G)) = (S_x(f(x,y))(S_y(f(x,y))|_{x=1;y=1} = \dfrac{11n^2+23n+16}{48n}$,

(iv) $SSD(\mu(G)) = (D_xS_y(f(x,y)) + D_yS_x(f(x,y)))|_{x=1;y=1} = \dfrac{2n^3+39n^2-7n-12}{6n}$,

(v) $H(\mu(G)) = 2S_xJ(f(x,y))|_{x=1} = \dfrac{345n^3+2426n^2+3055n+846}{420n^2+2100n+2520}$,

(vi) $I(\mu(G)) = S_xJD_xD_y(f(x,y))|_{x=1} = \dfrac{885n^3+2372n^2-1070n-5388}{105n^2+525n+630}$. □

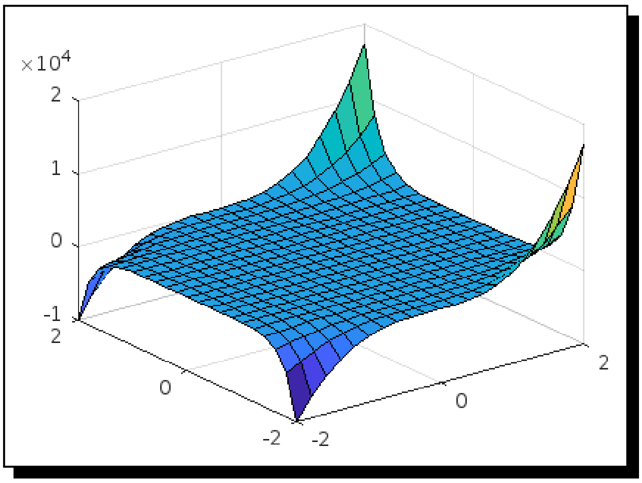


Figure 2. Plot of M-polynomial of Mycielskian of a path P_8

5. M-polynomial of Mycielskian of Cycles

We now find the M-polynomial of Mycielskian of cycles.

Theorem 5.1. *Let C_n be a cycle of order $n \geq 3$. Then $m(\mu(G))$ is*

$$M(\mu(G);x,y) = 2nx^3y^4 + nx^3y^n + nx^4y^4.$$

Proof. Let $G = C_n$ be a cycle of order n, $n \geq 3$. From Figure 1(b) it is easy to observe that

$$|V(\mu(G))| = 2n+1 \text{ and } |E(\mu(G))| = 4n.$$

Since each vertex of G is of degree either 2 or 4 or n, the partitions of $V(\mu(G))$ be:

$$V_1(\mu(G)) = \{a \in V(\mu(G)) : \deg_{\mu(G)}(a) = 3\},$$
$$V_2(\mu(G)) = \{a \in V(\mu(G)) : \deg_{\mu(G)}(a) = 4\},$$
$$V_3(\mu(G)) = \{a \in V(\mu(G)) : \deg_{\mu(G)}(a) = n\}.$$

Clearly,

$$|V_1(\mu(G))| = n, \quad |V_2(\mu(G))| = n, \quad |V_3(\mu(G))| = 1.$$

Furthermore, the partitions of edge set $E(\mu(G))$ are:

$$E_1(\mu(G)) = \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 3, \deg_{\mu(G)}(b) = 4\},$$
$$E_2(\mu(G)) = \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 3, \deg_{\mu(G)}(b) = n\},$$
$$E_3(\mu(G)) = \{e = ab \in E(\mu(G)) : \deg_{\mu(G)}(a) = 4, \deg_{\mu(G)}(b) = 4\}.$$

Clearly,

$$|E_1(\mu(G))| = 2n, \quad |E_2(\mu(G))| = n, \quad |E_3(\mu(G))| = n.$$

Therefore,

$$\begin{aligned} M(G;x,y) &= \sum_{\delta \leq \alpha \leq \beta \leq \Delta} m_{\alpha\beta}(\mu(G)) x^\alpha y^\beta \\ &= m_{34}(\mu(G))x^3y^4 + m_{3n}(\mu(G))x^3y^n + m_{44}(\mu(G))x^4y^4 \\ &= 2nx^3y^4 + nx^3y^n + nx^4y^4. \end{aligned}$$

□

Theorem 5.2. *Let C_n be a cycle of order $n \geq 3$. Then,*

$$M_1(\mu(G)) = n^2 + 25n,$$
$$M_2(\mu(G)) = 3n^2 + 40n,$$
$$^mM_2(\mu(G)) = \frac{11n+16}{48},$$
$$SSD(\mu(G)) = \frac{2n^2+37n+18}{6},$$
$$H(\mu(G)) = \frac{23n^2+125n}{28n+84},$$
$$I(\mu(G)) = \frac{59n^2+114n}{7n+21}.$$

Proof. From Theorem 5.1, we have

$$M(\mu(G);x,y) = 2nx^3y^4 + nx^3y^n + nx^4y^4.$$

Then,

$$D_x(f(x,y)) = 3nx^3y^n + 4nx^4y^4 + 6nx^3y^4,$$
$$D_y((f(x,y)) = n^2x^3y^n + 4nx^4y^4 + 8nx^3y^4,$$
$$(D_yD_x)(f(x,y)) = 3n^2x^3y^n + 16nx^4y^4 + 24nx^3y^4,$$
$$S_x(f(x,y)) = \frac{4nx^3y^n + (3nx^4 + 8nx^3)y^4}{12},$$
$$S_y(f(x,y)) = \frac{4x^3y^n + (nx^4 + 2nx^3)y^4}{4},$$
$$S_xS_y(f(x,y)) = \frac{16x^3y^n + (3nx^4 + 8nx^3)y^4}{48},$$
$$S_yD_x(f(x,y)) = \frac{6x^3y^n + (2nx^4 + 3nx^3)y^4}{2},$$
$$S_xD_y(f(x,y)) = \frac{n^2x^3y^n + (3nx^4 + 8nx^3)y^4}{3},$$
$$2S_xJ(f(x,y)) = \frac{(56nx^{n+3} + (7n^2+21n)x^8 + (16n^2+48n)x^7}{28n+84},$$
$$S_xJD_xD_y(f(x,y)) = \frac{21n^2x^{n+3} + (14n^2+42n)x^8 + (24n^2+72n)x^7}{7n+21}.$$

Now, we have the following:

(i) $M_1(\mu(G)) = (D_x(f(x,y) + D_y(f(x,y))|_{x=1;y=1} = n^2 + 25n$,

(ii) $M_2(\mu(G)) = (D_x(f(x,y))(D_y(f(x,y))|_{x=1;y=1} = 3n^2 + 40n$,

(iii) $^mM_2(\mu(G)) = (S_x(f(x,y))(S_y(f(x,y))|_{x=1;y=1} = \dfrac{11n+16}{48}$,

(iv) $SSD(\mu(G)) = (D_xS_y(f(x,y)) + D_yS_x(f(x,y)))|_{x=1;y=1} = \dfrac{2n^2+37n+18}{6}$,

(v) $H(\mu(G)) = 2S_xJ(f(x,y))|_{x=1} = \dfrac{23n^2+125n}{28n+84}$,

(vi) $I(\mu(G)) = S_x J D_x D_y(f(x,y))|_{x=1} = \dfrac{59n^2+114n}{7n+21}$. □

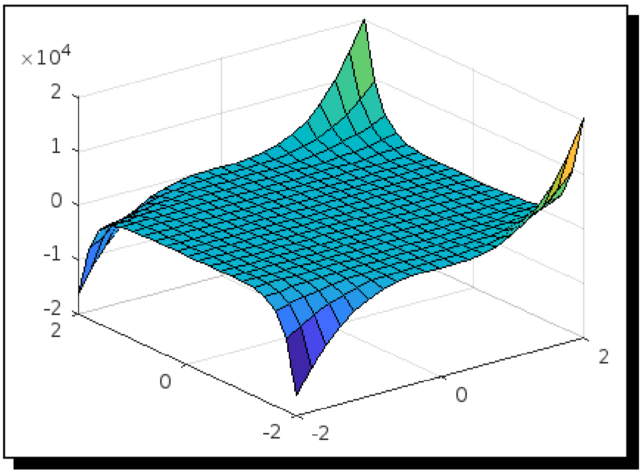


Figure 3. Plot of M-polynomial of Mycielskian of a cycle C_8

6. Conclusion

We have discussed the closest forms of M-polynomial for Mycielskian of paths and cycles. The graphical representation of M-polynomial is given and derived some degree-based topological indices from M-polynomial. The M-polynomial can be determined for many graph classes, derived graphs, graph products, graph operations, and graph powers.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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