

## Neighbourly Irregular Derived Graphs

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### ABSTRACT

A connected graph  $G$  is said to be neighbourly irregular graph if no two adjacent vertices of  $G$  have same degree. In this paper, we obtain neighbourly irregular derived graphs such as semitotal-point graph,  $k$ -th semitotal-point graph, semitotal-line graph, paraline graph, quasi-total graph and quasivertex-total graph and also neighbourly irregular of some graph products.

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## 1. INTRODUCTION AND PRELIMINARIES

In this paper, we are concerned with finite, simple, connected graph  $G$  with vertex set  $V(G) = \{v_1, v_2, \dots, v_n\}$  and edge set  $E(G) = \{e_1, e_2, \dots, e_m\}$ . If  $v_i$  and  $v_j$  are vertices of  $G$ , then the edge connecting them will be denoted by  $v_i v_j$ . The *degree* of a vertex  $v$  in  $G$  is denoted by  $d_G(v)$ . The *complement* of  $G$ , denoted by  $\overline{G}$ , is a graph which has the same vertex set as  $G$ , in which two vertices are adjacent if and only if they are not adjacent in  $G$  and  $d_{\overline{G}}(v) = n - 1 - d_G(v)$  holds for all  $v \in V(G)$ . Definitions not given here may be found in [4].

A graph  $G$  is said to be *regular* if all its vertices have the same degree. A connected graph  $G$  is said to be *highly irregular* if each neighbor of any vertex has different degree [1]. The graph  $G$  is said to be *neighbourly irregular graph*, abbreviated as *NI* graph, if no

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two adjacent vertices of  $G$  have the same degree. This concept was introduced by Bhraagsam and Ayyaswamy [2]. In [2, 12], authors constructed  $NI$  graphs of order  $n$  for a given  $n$  and a partition of  $n$  with distinct parts and proved some properties of  $NI$  graphs related to graphoidal covering number, gracefulness, ply number, lace number, clique graph, minimal edge covering and studied the neighbourly irregularity of some graph products.

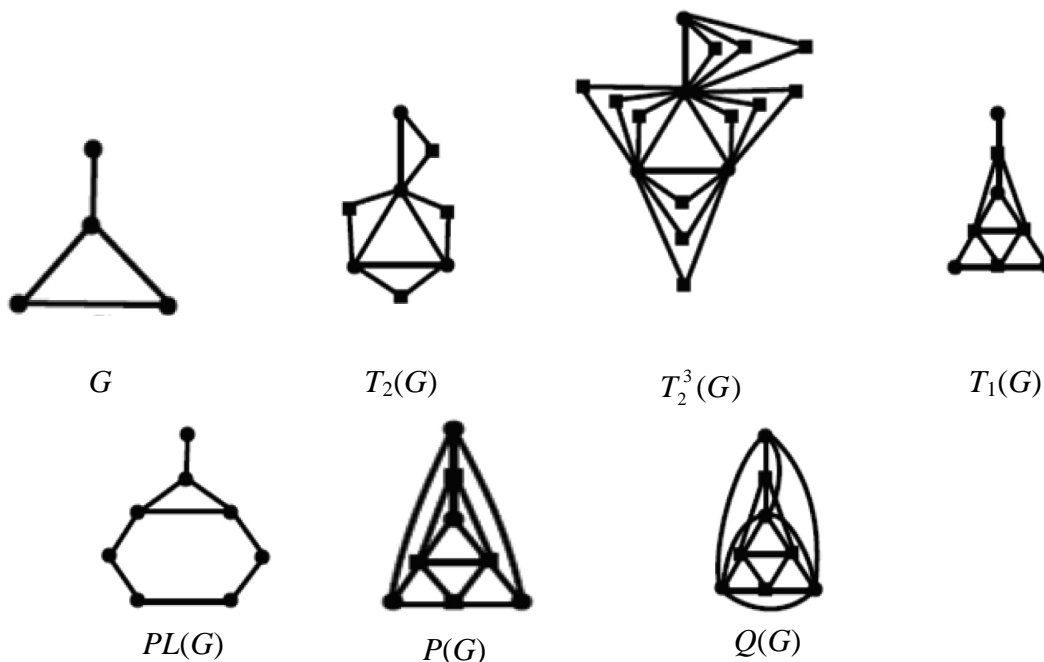
The *line graph*  $L(G)$  of a graph  $G$  is the graph with vertex set as the edge set of  $G$  and two vertices of  $L(G)$  are adjacent whenever the corresponding edges in  $G$  have a vertex in common. The *subdivision graph*  $S(G)$  of a graph  $G$  whose vertex set is  $V(G) \cup E(G)$  where two vertices are adjacent if and only if one is a vertex of  $G$  and other is an edge of  $G$  incident with it.

## 2. DERIVED GRAPHS

In this paper we considered the following graphs derived from the parent graph  $G$ :

1. The ***semitotal-point graph***  $T_2(G)$  as the graph [8] whose vertex set is  $V(G) \cup E(G)$  where two vertices are adjacent if and only if (i) they are adjacent vertices of  $G$  or (ii) one is a vertex of  $G$  and other is an edge of  $G$  incident with it. If  $u$  is a vertex of  $G$ , then  $d_{T_2(G)}(u) = 2d_G(u)$ . If  $e$  is an edge of  $G$ , then  $d_{T_2(G)}(e) = 2$ .
2. The ***k-th semitotal-point graph***  $T_2^k(G)$  of  $G$  [6] is the graph obtained by adding  $k$  vertices to each edge of  $G$  and joining them to the endvertices of the respective edge. Obviously, this is equivalent to adding  $k$  triangles to each edge of  $G$ .
3. The ***semitotal-line graph***  $T_1(G)$  as the graph [8] whose vertex set is  $V(G) \cup E(G)$  where two vertices are adjacent if and only if (i) they are adjacent edges of  $G$  or (ii) one is a vertex of  $G$  and other is an edge of  $G$  incident with it. If  $u$  is a vertex of  $G$ , then  $d_{T_1(G)}(u) = d_G(u)$ . If  $e = uv$  is an edge of  $G$ , then  $d_{T_1(G)}(e) = d_G(u) + d_G(v)$ .
4. The ***paraline graph***  $PL(G)$  is a line graph of subdivision graph of  $G$ .
5. The ***quasi-total graph***  $P(G)$  as the graph [9] whose vertex set is  $V(G) \cup E(G)$  where two vertices are adjacent if and only if (i) they are nonadjacent vertices of  $G$  or (ii) they are adjacent edges of  $G$  or (iii) one is a vertex of  $G$  and other is an edge of  $G$  incident with it. If  $u$  is a vertex of  $G$ , then  $d_{P(G)}(u) = n - 1$ . If  $e = uv$  is an edge of  $G$ , then  $d_{P(G)}(e) = d_G(u) + d_G(v)$ .
6. The ***quasivertex-total graph***  $Q(G)$  as the graph [7] whose vertex set is  $V(G) \cup E(G)$  where two vertices are adjacent if and only if (i) they are adjacent vertices of  $G$  or (ii) they are nonadjacent vertices of  $G$  (iii) they are adjacent edges of  $G$  or (iv) one is a vertex of  $G$  and other is an edge of  $G$  incident with it. If  $u$  is a vertex of  $G$ , then  $d_{Q(G)}(u) = n - 1 + d_G(u)$ . If  $e = uv$  is an edge of  $G$ , then  $d_{Q(G)}(e) = d_G(u) + d_G(v)$ .

In Figure 1 self-explanatory examples of these derived graphs are depicted.



**Figure 1.** Various graphs derived from the graph  $G$  and  $T_2^3(G)$  is  $k$ -th semitotal-point graph of  $G$  for  $k = 3$ .

The vertices of derived graphs depicted in Figure 1 except from the paraline graph  $PL$ , corresponding to the vertices of the parent graph  $G$ , are indicated by circles. The vertices of these graphs corresponding to the edges of the parent graph  $G$  are indicated by squares. In this paper we obtain neighbourly irregular derived graphs.

**Theorem 2.1** [12] Let  $G$  be a graph. The subdivision graph  $S(G)$  is NI if and only if  $G$  does not have any vertex of degree two.

**Theorem 2.2** [12] For any graph  $G$ , its line graph  $L(G)$  is NI graph if and only if  $N(u)$  contains all vertices of different degree for all  $u \in V(G)$ .

**Theorem 2.3** [2] If  $G$  is NI graph, then  $\overline{G}$  is not NI graph.

**Theorem 2.4** [12] If  $G$  is NI graph, then  $L(G)$  is not NI graph.

**Theorem 2.5** [12] For each integer  $k \geq 1$ , there exist a graph  $G$  with maximum degree  $\Delta(G) = k$  such that  $L(G)$  is NI graph.

### 3. RESULTS

**Theorem 3.1** For any graph  $G$ , the semitotal-point graph  $T_2(G)$  is NI if and only if  $G$  is NI graph and no vertex of degree one is in  $G$ .

**Proof.** Suppose  $G$  is NI graph and no vertex of degree one is in  $G$ . In  $T_2(G)$ , let  $e = xy$  be an edge. Then  $x, y \in V(G)$  or  $x \in V(G)$  and  $y \in E(G)$ .

- (a)  $x, y \in V(G)$ . Since  $d_G(x) \neq d_G(y)$ ,  $d_{T_2(G)}(x) = 2d_G(x) \neq 2d_G(y) = d_{T_2(G)}(y)$ .
- (b)  $x \in V(G)$  and  $y \in E(G)$ . Since no vertex of degree is one in  $G$  and  $d_{T_2(G)}(y) = 2$ ,  $d_{T_2(G)}(x) = 2d_G(x) \neq 2 = d_{T_2(G)}(y)$ . Thus from all the cases  $T_2(G)$  is NI graph.

Conversely, suppose  $G$  is not NI graph. Then  $d_G(x) = d_G(y)$  for some vertices  $x$  and  $y$  are adjacent in  $G$ . So,  $d_{T_2(G)}(x) = d_{T_2(G)}(y)$ . A contradiction to  $T_2(G)$  is NI graph. Suppose  $d_G(v) = 1$  for some  $v \in V(G)$ . Let  $e = vy$  be an edge in  $T_2(G)$ . Then  $d_{T_2(G)}(v) = 2d_G(v) = 2 = d_{T_2(G)}(y)$ . Again a contradiction to  $T_2(G)$  is NI graph.  $\square$

**Theorem 3.2** For any graph  $G$ , the  $k^{\text{th}}$  semitotal-point graph is NI if and only if  $G$  is NI graph and  $k \geq 2$ .

**Proof.** The proof of this theorem is similar to the proof of the Theorem 3.1, so is omitted.  $\square$

**Theorem 3.3** For any graph  $G$ , its  $T_1(G)$  is NI if and only if  $L(G)$  is NI graph.

**Proof.** Suppose  $L(G)$  is NI graph. In  $T_1(G)$ , let  $e = xy$  be an edge. Then  $x, y \in E(G)$  or  $x \in V(G)$  and  $y \in E(G)$ .

- (a)  $x, y \in E(G)$ . Let  $x = v_i v_j$  and  $y = v_i v_k$ , so that  $x$  and  $y$  are adjacent in  $T_1(G)$ . Since  $L(G)$  is NI graph, we have  $d_{L(G)}(x) \neq d_{L(G)}(y)$ ,  $d_G(v_i) + d_G(v_j) - 2 \neq d_G(v_i) + d_G(v_k) - 2$  or  $d_G(v_i) + d_G(v_j) \neq d_G(v_i) + d_G(v_k)$ . Therefore  $d_{T_1(G)}(x) \neq 2d_{T_1(G)}(y)$ .
- (b)  $x \in V(G)$  and  $y \in E(G)$ . Let  $e = xy = v_i e_j$  for some  $v_i \in V(G)$  and  $e_j \in E(G)$ . Therefore  $d_{T_1(G)}(x) = d_{T_1(G)}(v_i) = d_G(v_i)$  and  $d_{T_1(G)}(y) = d_{T_1(G)}(e_j) = d_G(v_i) + d_G(v_k)$  where  $e_j = v_i v_k \neq d_G(v_i)$  as  $d_G(v_k) \neq 0 = d_G(x) = d_{T_1(G)}(x)$ . Therefore for every pair of adjacent vertices in  $T_1(G)$  have different degree. Thus  $T_1(G)$  is NI graph.

Conversely, suppose  $L(G)$  is not NI graph. Then  $d_{L(G)}(e_i) = d_{L(G)}(e_j)$  for some  $e_i = v_r v_s$  and  $e_j = v_r v_k$  are adjacent vertices in  $L(G)$ . Hence,  $d_G(v_r) + d_G(v_s) - 2 = d_G(v_r) + d_G(v_k) - 2$ ,  $d_G(v_r) + d_G(v_s) = d_G(v_r) + d_G(v_k)$ . Therefore  $d_{T_1(G)}(e_i) = d_{T_1(G)}(e_j)$ . A contradiction to  $T_1(G)$  is NI graph.  $\square$

From Theorems 2.4, 2.5 and 3.3, we have the following corollaries.

**Corollary 3.4** If  $G$  is NI graph, then  $T_1(G)$  is not NI graph.

**Corollary 3.5** For each integer  $k \geq 1$ , there exists a graph  $G$  with maximum degree  $\Delta(G) = k$  such that  $T_1(G)$  is NI graph.

**Theorem 3.6** For any graph  $G \neq K_2$ , the paraline graph  $PL(G)$  is not NI graph.

**Proof.** Let  $v$  be a vertex of degree at least two in  $G$ . Then neighbourhood of  $v$  in  $S(G)$  has at least two vertices of degree two. By Theorem 2.2,  $L(S(G))=PL(G)$  is not NI graph.  $\square$

**Theorem 3.7.** For any graph  $G \neq K_2$ , the quasi-total graph  $P(G)$  is not NI graph.

**Proof.** Let  $G \neq K_2$  be a graph. We have the following cases:

**Case 1.** If  $G$  is not a complete graph, then there exist at least two vertices  $u, v \in V(G)$  such that  $d_{P(G)}(u) = d_{P(G)}(v) = n - 1$ . Therefore  $P(G)$  is not NI graph.

**Case 2.** If  $G$  is a complete graph, then there exist at least two edges  $e_i, e_j \in E(G)$  such that  $d_{P(G)}(e_i) = d_{P(G)}(e_j)$ . Therefore  $P(G)$  is not NI graph.  $\square$

**Theorem 3.8** For any graph  $G$  with  $n$  vertices, the quasivertex-total graph  $Q(G)$  is NI if and only if  $G, \bar{G}$  and  $L(G)$  all are NI graphs and  $\Delta(G) \neq n - 1$ .

**Proof.** Suppose  $G, \bar{G}$  and  $L(G)$  all are NI graphs. In  $Q(G)$ , let  $e = xy$  be an edge, then  $x, y \in V(G)$  or  $x, y \in V(\bar{G})$  or  $x, y \in E(G)$  or  $x \in V(G)$  and  $y \in E(G)$ .

(a)  $x, y \in V(G)$ . Since  $d_G(x) \neq d_G(y)$ ,  $d_{Q(G)}(x) = n - 1 + d_G(x) \neq n - 1 + d_G(y) = d_{Q(G)}(y)$ .

(b)  $x, y \in V(\bar{G})$ . Since  $d_{\bar{G}}(x) \neq d_{\bar{G}}(y)$ ,  $d_{Q(G)}(x) = n - 1 + d_G(x) \neq n - 1 + d_G(y) = d_{Q(G)}(y)$ .

(c)  $x, y \in E(G)$ . Let  $x = v_i v_j$  and  $y = v_i v_k$ . So that  $x$  and  $y$  are adjacent in  $Q(G)$ . Therefore  $d_{Q(G)}(x) = d_G(v_i) + d_G(v_j)$  and  $d_{Q(G)}(y) = d_G(v_i) + d_G(v_k)$ . But  $d_{L(G)}(x) \neq d_{L(G)}(y)$  as  $L(G)$  is NI graph,  $d_{L(G)}(x) = d_G(v_i) + d_G(v_j) - 2$  and  $d_{L(G)}(y) = d_G(v_i) + d_G(v_k) - 2$ . Therefore  $d_{Q(G)}(x) \neq d_{Q(G)}(y)$ .

(d)  $x \in V(G)$  and  $y \in E(G)$ . Let  $e = xy = v_i e_j$  for some  $v_i \in V(G)$  and  $e_j \in E(G)$ . Then  $d_{Q(G)}(y) = d_{Q(G)}(e_j) = d_{L(G)}(e_j) + 2$  where  $e_j = v_i v_j = d_G(v_i) + d_G(v_j) \neq n - 1 + d_G(v_i)$  as  $\Delta(G) \neq n - 1 \neq d_{Q(G)}(x)$ . Thus in all the cases  $Q(G)$  is NI graph.

Conversely, suppose  $Q(G)$  is NI graph. We have to prove that  $G, \bar{G}$  and  $L(G)$  are all NI graphs. If  $G$  is not NI graph, then there exists an edge  $e_k = v_i v_j$  in  $G$  such that  $d_G(v_i) = d_G(v_j)$ . Therefore  $n - 1 + d_G(v_i) = n - 1 + d_G(v_j)$ . So,  $d_{Q(G)}(v_i) = d_{Q(G)}(v_j)$ . A contradiction

to  $Q(G)$  is NI graph. Suppose  $\bar{G}$  is not NI graph, then there exists an edge  $e_k = v_i v_j$  in  $\bar{G}$  such that  $d_{\bar{G}}(v_i) = d_{\bar{G}}(v_j)$ . Therefore  $n - 1 + d_G(v_i) = n - 1 + d_G(v_j)$  and so  $d_{Q(G)}(v_i) = d_{Q(G)}(v_j)$ . A contradiction to  $Q(G)$  is NI graph.

Suppose  $L(G)$  is not NI graph, then there exists two adjacent vertices  $e_i = v_r v_s$  and  $e_j = v_r v_k$  in  $L(G)$  with  $d_{L(G)}(e_i) = d_{L(G)}(e_j)$ . Thus  $d_G(v_r) + d_G(v_s) - 2 = d_G(v_r) + d_G(v_k) - 2$ . Hence  $d_G(v_r) + d_G(v_s) = d_G(v_r) + d_G(v_k)$  and so  $d_{Q(G)}(e_i) = d_{Q(G)}(e_j)$ . Again a contradiction to  $Q(G)$  is NI graph. Suppose  $\Delta(G) = n - 1 = d_G(v)$  and let  $e = uv$  be an edge. Then  $d_{Q(G)}(e) = d_{Q(G)}(u)$ . Again a contradiction to  $Q(G)$  is NI graph.  $\square$

From Theorems 2.3, 2.4 and 3.8 we have following result.

**Theorem 3.9** There is no nontrivial graph  $G$  whose quasivertex-total graph  $Q(G)$  is NI graph.

#### 4. NEIGHBOURLY IRREGULAR GRAPH PRODUCTS

The corona [10] of two graphs  $G$  and  $H$  is the graph obtained by taking one copy of  $G$ ,  $|V(G)|$  copies of  $H$  and joining each  $i$ -th vertex of  $G$  to every vertex in the  $i$ -th copy of  $H$ . The edge corona [5] of two graphs  $G$  and  $H$  denoted by  $G \diamond H$  is obtained by taking one copy of  $G$  and  $|E(G)|$  copies of  $H$  and joining each end vertices of  $i$ -th edge of  $G$  to every vertex in the  $i$ -th copy of  $H$ .

**Theorem 4.1** Let  $G$  and  $H$  be nontrivial graphs. Then  $G \diamond H$  is NI graph if and only if both  $G$  and  $H$  are NI graphs and,  $G$  does not have pendent vertex or  $\Delta(H) < |V(H)| - 1$ , where  $\Delta(H)$  is the maximum degree of the vertices of  $H$ .

**Proof.** To prove the result, we have to present some notations. Let  $G'$  be the copy of  $G$  and  $H_i$  be the  $i$ -th copy of  $H$  in  $G \diamond H$ ,  $1 \leq i \leq |E(G)|$ . A vertex of  $G \diamond H$  corresponding to the vertex  $u$  in  $H$  is denoted by  $u'$ . Also, we denote a vertex of  $G \diamond H$  corresponding to the vertex  $v$  in  $G$  by  $v'$ .

Let  $G$  and  $H$  be NI graphs and,  $G$  does not have pendent vertex or  $\Delta(H) < |V(H)| - 1$ . Then it is clear that  $G \diamond H$  is NI graph.

Conversely, let  $G$  and  $H$  be two nontrivial graphs and  $G \diamond H$  is NI graph. Suppose  $u'v' \in E(G \diamond H)$  such that  $u', v' \in V(H_i)$ , then  $d_{G \diamond H}(u') - d_{G \diamond H}(v') = d_H(u) - d_H(v) \neq 0$  and so  $H$  is NI graph. Also, if  $u'v' \in E(G \diamond H)$  such that  $u', v' \in V(G')$ , then  $d_{G \diamond H}(u') - d_{G \diamond H}(v') = (|V(H)| + 1)(d_G(u) - d_G(v)) \neq 0$ . Thus,  $G$  is NI graph. On the other hand, if  $u'v' \in E(G \diamond H)$  such that  $u' \in V(G')$ , and  $v' \in V(H_i)$ , then  $d_{G \diamond H}(u') - d_{G \diamond H}(v') = (|V(H)| + 1)$

$d_G(u) - (d_H(v) + 2) \neq 0$  and it shows that,  $G$  does not have pendent vertex or  $\Delta(H) < |V(H)| - 1$ . □

To present the next results, we need two definitions as follows: The cluster  $G\{H\}$  is obtained by taking one copy of  $G$  and  $|V(G)|$  copies of a rooted graph  $H$ , and by identifying the root of the  $i$ -th copy of  $H$  with the  $i$ -th vertex of  $G$ ,  $i = 1, 2, \dots, |V(G)|$  [11].

Suppose  $G$  and  $H$  are graphs with disjoint vertex sets. Following Došlić [3], for given vertices  $y \in V(G)$  and  $z \in V(H)$  a splice of  $G$  and  $H$  by vertices  $y$  and  $z$ ,  $(G \cdot H)(y, z)$ , is defined by identifying the vertices  $y$  and  $z$  in the union of  $G$  and  $H$ .

**Theorem 4.2** Let  $G$  and  $H$  be graphs. Then  $G\{H\}$  is NI graph if and only if both  $G$  and  $(H \cdot S_{d_G(u_i)})(r, x)$  are NI graphs, for each  $i = 1, 2, \dots, |V(G)|$ , where  $x$  is the vertex with maximum degree of the star  $S_{d_G(u_i)}$  and  $r$  the root vertex of  $H$ .

**Proof.** Let  $G$  and  $(H \cdot S_{d_G(u_i)})(r, x)$  be NI graphs, for each  $i = 1, 2, \dots, |V(G)|$ , where  $x$  is the vertex with maximum degree of the star  $S_{d_G(u_i)}$  and  $r$  the root vertex of  $H$ . Then, it is clear that  $G\{H\}$  is NI graph.

Conversely, let  $G\{H\}$  be NI graph. Also, suppose  $u'v' \in E(G\{H\})$  and  $u', v'$  are the vertices of  $G\{H\}$  corresponding to the vertices  $u, v$  in  $G$ , respectively. If  $u'$  and  $v'$  are vertices of a copy of  $G$ , then  $d_{G\{H\}}(u') - d_{G\{H\}}(v') = d_G(u) - d_G(v) \neq 0$ . So  $G$  is NI graph. On the other hand, suppose  $u'v' \in E(G\{H\})$  and  $u', v'$  are the vertices of  $G\{H\} \cap H_i$  corresponding to the vertices  $u, v$  in  $H$ , respectively. Then, it is not difficult to see that  $d_{G\{H\}}(u') - d_{G\{H\}}(v') \neq 0$  if and only if

$$d_{(H \cdot S_{d_G(u_i)})(r,x)}(u) - d_{(H \cdot S_{d_G(u_i)})(r,x)}(v) \neq 0.$$

So,  $(H \cdot S_{d_G(u_i)})(r, x)$  is NI graph. □

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## Neighbourly Irregular Derived Graphs

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### گراف‌های مشتق‌شده همسایه‌وار نامنظم

ادیتور رابط : تومیسلاو داسلیک

#### چکیده

یک گراف همبند  $G$ ، همسایه‌وار نامنظم نامیده می‌شود هرگاه هیچ دو رأس مجاور  $G$ ، هم‌درجه نباشند. در این مقاله، گراف‌های مشتق‌شده همسایه‌وار نامنظم مانند گراف نیم‌کامل-نقطه، گراف نیم‌کامل-نقطه  $k$ - $m$ ، گراف نیم‌کامل-خط، گراف خط‌خطی، گراف شبه‌کامل، گراف شبه‌رأس کامل و همچنین برخی گراف‌های حاصلضربی را به دست می‌آوریم.

لغات کلیدی: همسایه‌وار نامنظم، گراف‌های مشتق‌شده، گراف‌های حاصلضربی