JTAM (Jurnal Teori dan Aplikasi Matematika)
http://journal.ummat.ac.id/index.php/jtam
p-ISSN 2597-7512 | e-ISSN 2614-1175
Vol. 5, No. 2, October 2021, pp. 294-304

Automatic Aircraft Navigation Using Star Metric Dimension Theory in Fire Protected Forest Areas

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Article History:
Received : 16-03-2021
Revised : 30-04-2021
Accepted : 01-05-2021
Online : 26-10-2021

Keyword:
Forest Fires;
Unique Graphs;
Stars Metric Dimensions.

ABSTRACT

The purpose of this research is to determine the navigation of an unmanned aircraft automatically using theory of the metric dimension of stars in a forest fire area. The research will also be expanded by determining the star metric dimensions on other unique graphs and graphs resulting from amalgamation operations. The methods used in this research are pattern recognition and axiomatic deductive methods. The pattern detection method is to look for patterns to construct differentiated sets on the metric dimension (dim) so that the coordinate values are minimum and different. Meanwhile, axiomatic deductive is a research method that uses deductive proof principles that apply in mathematical logic by using existing axioms or theorems to solve a problem. Then the method is used to determine the stars' metric dimensions. The result of conclusions on this research are The star graph's metric dimension value $\mathrm{Amal}(L_m, v, n)$ is $\mathrm{sdim}\left(\mathrm{Amal}(L_m, v, n)\right) = 2n + 1$, with $m \geq 2$ and $n \geq 2$, The star graph's metric dimension value $\mathrm{Amal}(S_m, v, n)$ is $\mathrm{sdim}\left(\mathrm{Amal}(S_m, v, n)\right) = 2n - 1$, with $m \geq 2$ and $n \geq 2$ and Representation the graph of the area of Fire Forest Land is obtained basis $Zs = \{13,14,15,16,17,18\}$, the number of coordinate points $|Zs| = 6$, $\mathrm{sdim} = 6$.

Crossref
https://doi.org/10.31764/jtam.v5i2.4331

A. INTRODUCTION

Forest is a plant community dominated by trees or other woody plants, growing together and quite tightly. Different and more detailed definitions are conveyed by (Gazol, Sangüesa-Barreda, Granda, & Camarero, 2017). Forests are a natural resource that is very useful for improving the people's economy from timber and non-timber products; however, the existence of forest resources in Indonesia has experienced decreasing quality and quantity in recent decades. The decline was caused by damage to forest resources such as forest plunder, forest fires, and poor human behavior towards forests. The demand for wood in Indonesia increases every year, and it is estimated that Indonesia's national wood demand reaches more than 60 million m^3. Fifty percent of the wood demand is used as raw material for the plywood or plywood industry (Halawane, Hanif, & Kinho, 2011). In recent years, Indonesia has experienced forest fires in Sumatra, Kalimantan, Papua, and even in Java; around October, the area leading to Ijen crater tourism has also experienced fires. It has caused nearly one million people to suffer from breathing disturbance due to forest fire smoke mentioned in kompas.com (Hakim & Galih, 2019). According to the Ministry of Environment and Forestry, based on Landsat satellite imagery, until September 2019, forest and land fires reached

857,755 hectares. For mineral land 630,451 hectares, and peatland 227,304 hectares (Mubarok, 2019). It requires unique prevention so that it does not repeatedly occur every year when the dry season begins.

One of the field studies that can be applied to prevent forest fires is, as explained earlier, related to the research focus on innovation and technology, namely Graph theory. In this case, one of the field studies of graph theory, namely the stars metric dimensions, will be used as the underlying theory for determining automatic drone navigation to prevent forest fires in certain areas. Graph theory emerges to solve problems in everyday life such as domination numbers are used to determine the number of CCTV installations in a building, field coloring on the graph is used to distinguish areas on the map, labeling is used to adjust scheduling, and metric dimensions can be applied to determine navigation robots and to install fire alarm in a building (Epstein, Levin, & Woeginger, 2015), (Rodríguez-Velázquez, García Gómez, & Barragán-Ramírez, 2015), (Kuziak, Rodriguez-Velazquez, & Yero, 2017).

Forest areas can be modeled into a graph by representing springs and locations prone to hotspots as vertex, while the roads between locations are modeled as an edge. Formally, a graph G is defined as a set pair$(V(G), E(G))$, where $V(G)$ an infinite set of elements called vertexes, and $E(G)$ is a (possibly empty) set of unordered pairs $\{u, v\}$ of vertexes $u, v \in V(G)$ called sides. Metric dimension is one of the developing graph theory concepts. Harary & Melter, 1976 has built the basic concepts and dimensions in the graph. A base in the graph is a set of vertexes with minimal cardinality, making each vertex on the graph have a different representation for each of these bases (Peterin & Yero, 2020). Harary defines the representation of vertexes using the concept of distance (metric) in the graph so that the basic cardinality in the graph is called the metric dimension. There are several studies that have been conducted regarding the Metric Dimension, and its application as about Base size, metric dimension and other invariants of groups and graphs (Bailey & Cameron, 2011); The (Weighted) Metric Dimension of Graphs: Hard and Easy Cases (Epstein et al., 2015); Approximation complexity of Metric Dimension problem (Hauptmann, Schmied, & Viehmann, 2012); Graphs with the edge metric dimension smaller than the metric dimension (Knor, Majstorović, Masa Toshi, Škrekovski, & Yero, 2021); Mixed metric dimension of graphs (Kelenc, Kuziak, Taranenko, & G. Yero, 2017); Metric dimension for random graphs (Bollobás, Mitsche, & Prałat, 2013); The metric dimension of the lexicographic product of graphs (Jannesari & Omoomi, 2012); On the strong metric dimension of corona product graphs and join graphs (Kuziak, Yero, & Rodríguez-Velázquez, 2013);

In this research, the concept of the metric dimension is developed into the star metric dimension. It means that every graph searched for the star metric dimensions must have a base in the form of a star graph with a different representation of each vertex (Filipović, Kartelj, & Kratica, 2019), (Cáceres, Hernando, Mora, Pelayo, & Puertas, 2012), (Yi, 2013) and (Nasir, Zafar, & Zahid, 2018). (Mutianingsih, Asrining dan Uzlifah 2016) defines the star metric dimensions and determines the star metric dimensions of a wheel-like graph. The representation of each vertex is analogous to an airplane's coordinates, while the base in the form of a star graph is likened to the aircraft control center and the location of the water source to prevent forest fires. This research will also discuss the characteristics or properties and value of star metric dimensions on unique graphs. Forests and lands are the research object, namely South Sumatra Province. The forest and land are chosen as research objects because there are fires every year (MIB, 2019). So it requires alternative handlers in tackling fires before land fires spread and cause haze disasters that can disrupt public health and activities. Since this topic has not been widely investigated, so in its application to automatic aircraft navigation, research will also be extended by determining the star metric dimensions in graphs resulting from amalgamation operations. The graphs that will be used in this research are star metric dimensions graph Result of Vertex Amalgamation operation of Ladder graph $Amal(L_m, v, n)$ with $m \geq 2$ and $n \geq 2$ and the graph resulting from the vertex Amalgamation operation of the Star graph with its name $Amal(S_m, v, n)$ with $m \geq 2$ and $n > 2$.

B. METHODS

1. Research Method

The methods used in this research are pattern recognition and axiomatic deductive methods. The pattern recognition method is to look for patterns to construct differentiated sets on the metric dimension (dim) so that the coordinate values are minimum and different (Saputro, Suprijanto, Baskoro, & Salman, 2012). Meanwhile, axiomatic deductive is a research method that uses deductive proof principles that apply in mathematical logic by using existing axioms or theorems to solve a problem. Then the method will determine the star metric dimensions of a graph similar to the wheel. Because this topic has not been widely investigated, so in its application to automatic aircraft navigation, research will also be extended by determining the star metric dimensions in graphs resulting from amalgamation operations.

2. Amalgamation Operation

For example $\boldsymbol{G_i}$, it is a set of finite graphs, and each graph $\boldsymbol{G_i}$ has a fixed vertex $\boldsymbol{v_{oi}}$, which is called a terminal. Amalgamation $\boldsymbol{Amal\{G_i, v_{oi}\}}$ is formed by joining all the graphs $\boldsymbol{G_i}$ on the terminal vertices $\boldsymbol{v_{oi}}$ (Kurniawati, Agustin, Dafik, Alfarisi, & Marsidi, 2018), and (Belmonte, Fomin, Golovach, & Ramanujan, 2017). The amalgamation operation in this study uses vertex amalgamation. The graph resulting from the vertex amalgamation operation is notated $\boldsymbol{Amal(G, v, t)}$ that amalgamation is constructed from any graph G as many copies t and joins all graphs G at terminal vertices v. The graph of the point amalgamation operation can be seen in Figure 1.

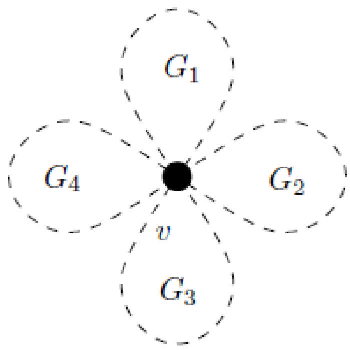

Figure 1. Graph of Vertex Amalgamation Operation Result $Amal(G, v, t)$

3. Metric Dimension

Definition 1. Supposed G that is a connected graph with the order n, $W = \{w_1, w_2, \dots, w_n\} \subseteq (G)$ is ordered set from on v is the the vertex G. The representations of vertex v against W are *k-tuple* ordered pairs, $r(v|W) = (d(v, w_1), d(v, w_2), \dots., d(v, w_n))$ (Jiang & Polyanskii, 2019), (Budianto & Kusmayadi, 2018), (Rodríguez-Velázquez, Kuziak, Yero, & Sigarreta, 2015).

With $d(v, w)$ is the distance between the vertex v and w. The set W is called the specific set of G if each vertex G has a different representation for W. The set of differentiators having minimal cardinality is called the **basis**. The number of points on the base of the graph G is called a **dimension**, denoted by $\dim(G)$. Furthermore because the dimensional concept in this graph is built using distance (metric), it is called the **metric dimension**.

In his research, Chartrand discovered the metric dimensions of several graphs. Chartrand's results showed part of it was a metric dimension characterization of several graphs, and the following was presented in Theorem 2

Theorem 2. Supposed G a connected graph has an order $n \geq 2$, then it applies

1) $\dim(G) = 1$ if only if $G = P_n$
2) $\dim(G) = n - 1$ if only if $G = K_n$
3) For $n \geq 4$, $\dim(G) = n - 2$ if only if $G = K_{r,s};\ (r; s\ \geq 1), G = K_r + K_s, (r \geq 1; S \geq 2)$ or $, G = K_r + (K_1 \cup K_s),\ (r; s \geq 1)$.

For $n \geq 3, \dim(C_n) = 2$.

4. Star Metric Dimension

Definition 3. If the vertices form a star graph, then the specific set $Z = \{Z_1, Z_2, Z_3, \dots, Z_k\}$ is called the star distinguishing set and is denoted by Z_s. The set of distinguishing stars with the minimum number of members is called the star metric dimension and is notated $sdim(G)$. Thus, the star metric dimension is the minimum number of star distinguishing sets G (Mutia, 2015) and (Saputro et al., 2012).

5. Operational Definition

The operational definition of variables is used to provide a systematic description of the research and avoid differences in meaning. In the discussion of metric dimensions, connected and undirected graphs will be used. Here are defined few unique graphs that will be used and their applications, namely:

a. Star Graph is a complete bipartite graph $K_{1,n}$. Next, the star graph with $n + 1$ vertex is denoted by S_n with $n \geq 1$.

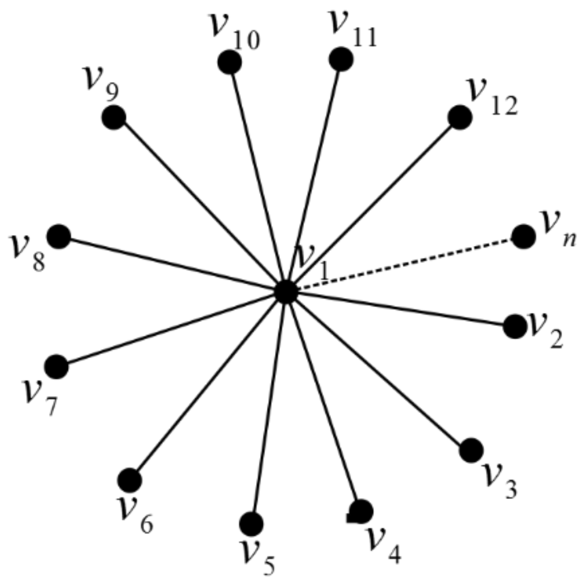

Figure 2. Star Graph S_n

b. Ladder Graph is a graph formed from the Cartesian product of a path graph with two vertexes and a path graph with n vertex. The ladder graph is denoted by $\boldsymbol{L_n}$, so $\boldsymbol{L_n} = \boldsymbol{P_2} \times \boldsymbol{P_n}$ (Handa, Godinho, & Singh, 2017).

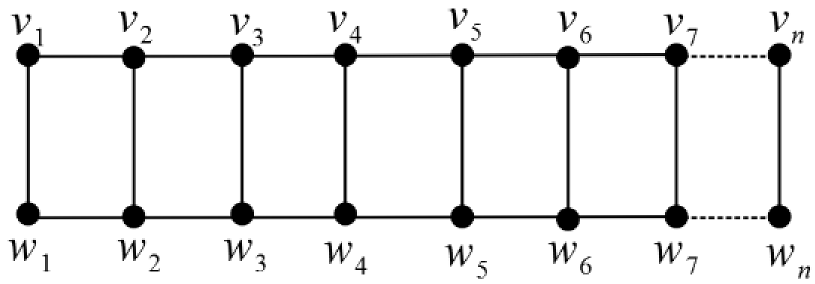

Figure 3. Ladder graph L_n

The application of metric dimensions to which automatic navigation coordinates will be determined to tackle land fires, namely maps and land fires in South Sumatra Province. Below is a map image of the forest and land that is the research object.

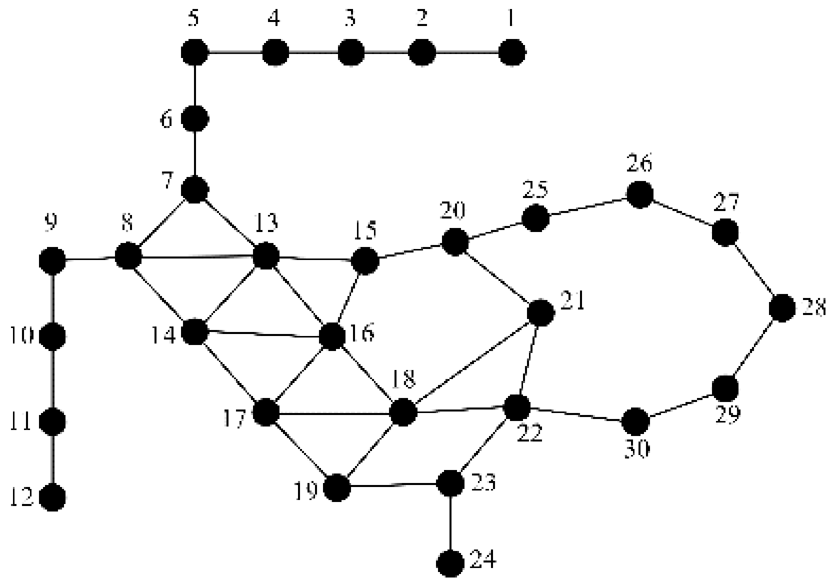

Figure 4. Forest and Land Map of South Sumatra Province with points as plane coordinate

6. Conceptual Framework

Figure 5 shows that in this study, the graph's metric dimensions are studied into two parts, namely the metric dimension and the fractional metric dimension. The metric dimensions are divided into metric dimensions, local metric dimensions, neighborhood metric dimensions, neighborhood metric dimensions, vital metric dimensions, star metric dimensions. Each of these development topics has been carried out much research, especially in graph diversity, except for the star metric dimensions. The metric dimension of the star has not been studied much in terms of graph development. There is only one study in the Star metric dimension, namely the Star metric dimension in a Wheel-like Graph (Mutianingsih, Asrining dan Uzlifah 2016).

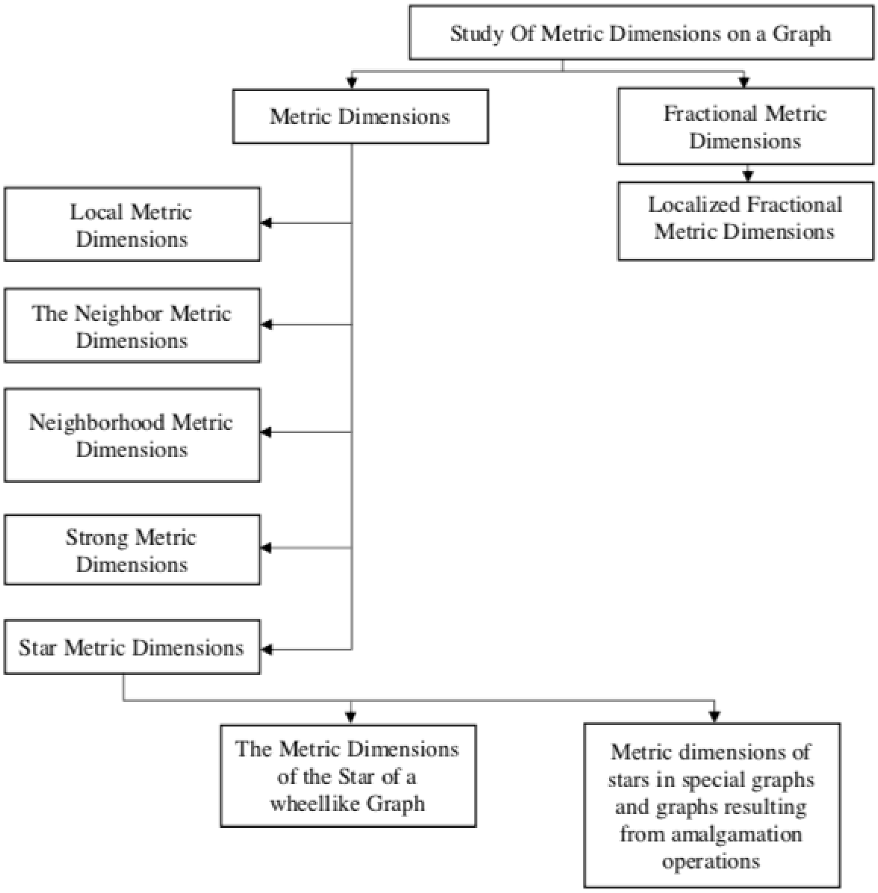

Figure 5. Research Concept Framework

C. RESULT AND DISCUSSION

This section will explain the results of the star metric dimensions graph Result of Vertex Amalgamation operation of Ladder graph $Amal(L_m, v, n)$ with $m \geq 2$ and $n \geq 2$ and the graph resulting from the vertex Amalgamation operation of the Star graph with its name $Amal(S_m, v, n)$ with $m \geq 2$ and $n > 2$. In this result there is a theorem and its proof. In addition, it will discuss the application of the star metric dimensionsAutomatic Navigation of Unmanned Aircraft in Fire Prone Forest Areas. Below are the results that have been obtained.

1. Star Metric Dimension of a Graph $\boldsymbol{Amal(L_m, v, n)}$

The graph resulting from the point Amalgamation operation of the Ladder graph is denoted by $Amal(L_m, v, n)$. The following below is the Star Metric Dimension Theorem generated from the graph $Amal(L_m, v, n)$ with $m \geq 2$ and $n \geq 2$.

◊ **Theorem 1** *The metric dimension value for the star graph $Amal(L_m, v, n)$ is $sdim\big(Amal(L_m, v, n)\big) = 2n + 1$, with $m \geq 2$ and $n \geq 2$.*

Proof.

Graph Amalgamation results of vertexes from the Ladder graph $Amal(L_m, v, n)$ with $m \geq 2$ and $n \geq 2$ have $V\big(Amal(L_m, v, n)\big) = \{\{A\}; \{x_{i,j}; 1 \leq i \leq n \; and \; 2 \leq j \leq n\}; \{y_{i+1,j+1}; 1 \leq i \leq n \; and \; 2 \leq j \leq n\}\}$ and $|V| = 2mn - n + 1$. As for $\big(Amal(L_m, v, n)\big) = \{\{Ax_{1,j}; 1 \leq j \leq$

$n\}; \{x_{i,j}y_{i,j}; 2 \le i \le n \; and \; 2 \le j \le n\}; \{x_{i,j}x_{i+1,j}; 1 \le i \le n \; and \; 1 \le j \le n\}; \{Ay_{2,j}; 1 \le j \le n\}; \{y_{i,j}y_{i+1,j}; 2 \le i \le n \; and \; 1 \le j \le n\}\}$ and $|E| = mn + (m_1n_1)(m-1)$.

To with $m \ge 2$ and $n \ge 2$ will be proved that $sdim\big(Amal(L_m, v, n)\big) \ge 2n + 1$. If it is cardinality $sdim\big(Amal(L_m, v, n)\big) \ge (2n+1) - 1$, if it is cardinality, then it is definitely not a set of distinctions and at least two representations are the same. There is at least for $2n+1$ vertex which the set of differentiators, so that $sdim\big(Amal(L_m, v, n)\big) \ge 2n + 1$. Meanwhile, to find the upper limit or $sdim\big(Amal(L_m, v, n)\big) \le 2n + 1$, so a construction is carried out. For example we take the set of differentiators $W = \{\{A\}; \{x_{i,j}; i = 1 \; and \; 1 \le j \le n\}; \{y_{i+1,j}; i = 1 \; and \; 1 \le j \le n\}\}$ and $|W| = 2n + 1$, so that the representation of vertex $V(Amal(L_m, v, n))$ to W has different coordinates and has minimal cardinality is obtained $sdim\big(Amal(L_m, v, n)\big) \le 2n + 1$. Hence $sdim\big(Amal(L_m, v, n)\big) \ge 2n + 1$ and $sdim\big(Amal(L_m, v, n)\big) \ge 2n + 1$ therefore $sdim\big(Amal(L_m, v, n)\big) = 2n + 1$. ■

To be more sure given a graph $Amal(L_4, v, 2)$ where $W = \{A, x_{1,1}, x_{1,2}, y_{2,1}, y_{2,2}\}$, so $sdim\big(Amal(L_4, v, 2)\big) = 5$. The coordinates of all vertexes in $Amal(L_4, v, 2)$ against W is
$r(A|W) = (1,0,1,1,1)$ $r(x_{1,2}|W) = (2,1,2,0,2)$ $r(x_{1,1}|W) = (0,1,2,2,2)$ $r(x_{2,2}|W) = (3,2,3,1,1)$

$r(x_{2,1}\|W) = (1,2,1,3,3)$	$r(x_{3,2}\|W) = (4,3,4,2,2)$
$r(x_{3,1}\|W) = (2,3,2,4,4)$	$r(x_{4,2}\|W) = (5,4,5,3,3)$
$r(x_{4,1}\|W) = (3,4,3,5,5)$	$r(y_{2,2}\|W) = (2,1,2,2,0)$
$r(y_{2,1}\|W) = (2,1,0,2,2)$	$r(y_{3,2}\|W) = (3,2,3,3,1)$
$r(y_{3,1}\|W) = (3,2,1,3,3)$	$r(y_{4,2}\|W) = (4,3,14,4,2)$
$r(y_{4,1}\|W) = (4,3,2,4,4)$	

Below is Figure 6 of the graph $Amal(L_4, v, 2)$.

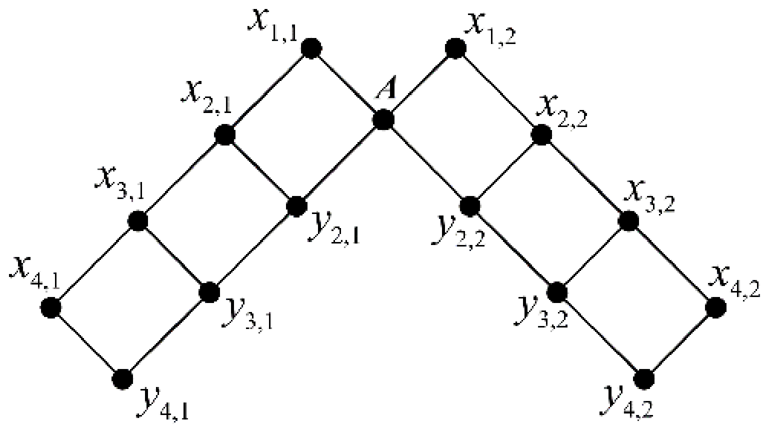

Figure 6. The Graph $Amal(L_4, v, 2)$

2. A Graph of Star Metric Dimension $Amal(S_m, v, n)$

The graph resulting from the vertex Amalgamation operation of the star graph is denoted by $Amal(S_m, v, n)$. The following below is the Star Metric Dimension Theorem generated from the graph $Amal(S_m, v, n)$ with $m \ge 2$ and $n \ge 2$.

◊ **Theorem 2** *The value of the metric dimension of the star graph* $Amal(S_m, v, n)$ *is* $sdim\big(Amal(S_m, v, n)\big) = 2n - 1$, *with* $m \ge 2$ *and* $n \ge 2$.

Proof.
Graph Amalgamation results of the vertex of the Star graph $Amal(S_m, v, n)$ with $m \geq 2$ and $n \geq 2$ have $V\big(Amal(S_m, v, n)\big) = \{\{A\}; \{c_i; 1 \leq i \leq n\}; \{x_{i-1,j}; 3 \leq i \leq n \; and \; 2 \leq j \leq n\}\}$ and $|V| = mn + 1$. As for $E\big(Amal(S_m, v, n)\big) = \{\{Ac_i; 1 \leq i \leq n\}; \{c_i x_{i-1,j}; 3 \leq i \leq n \; dan \; 2 \leq j \leq n\}$ and $|V| = mn$.

To with $m \geq 2$ and $n \geq 2$ will be proved that $sdim\big(Amal(S_m, v, n)\big) \geq 2n - 1$. If it is cardinality $sdim\big(Amal(S_m, v, n)\big) \geq (2n - 1) - 1$, then it is definitely not a set of distinctions and at least two representations are the same. There is at least for that $2n - 1$ vertex which is the set of differentiators, so $sdim\big(Amal(S_m, v, n)\big) \geq 2n - 1$. Meanwhile, to find the upper limit or $sdim\big(Amal(S_m, v, n)\big) \leq 2n - 1$, a construction is carried out. For example, we take the set of differentiators $W = \{\{A\}; \{c_i; 1 \leq i \leq n\}; \{x_{i-2,j}; 1 \leq i \leq n \; dan \; 1 \leq j \leq n\}\}$ and $|W| = 2n - 1$, so that the representation of vertex $V(Amal(S_m, v, n))$ to W has different coordinates and has minimal cardinality is obtained $sdim\big(Amal(S_m, v, n)\big) \leq 2n - 1$. Hence $sdim\big(Amal(S_m, v, n)\big) \geq 2n - 1$ and $sdim\big(Amal(S_m, v, n)\big) \geq 2n - 1$ therefore $sdim\big(Amal(S_m, v, n)\big) = 2n - 1$. ■

To be more sure given a graph $Amal(S_5, v, 2)$ where $W = \{A, c_1, c_2, x_{1,1}, x_{2,1}, x_{3,1}, x_{1,2}, x_{2,2}, x_{3,2}\}$, so $sdim\big(Amal(S_5, v, 2)\big) = 9$. The coordinates of all vertexes in $Amal(S_5, v, 2)$ against W is

$r(A|W) = (0,1,2,2,2,1,2,2,2)$
$r(c_1|W) = (1,0,1,1,1,2,3,3,3)$
$r(c_2|W) = (1,2,3,3,3,0,1,1,1)$
$r(x_{1,1}|W) = (2,1,0,2,2,3,4,4,4)$
$r(x_{2,1}|W) = (2,1,2,0,2,3,4,4,4)$
$r(x_{3,1}|W) = (2,1,2,2,0,3,4,4,4)$
$r(x_{4,1}|W) = (2,1,2,2,2,3,4,4,4)$
$r(x_{1,2}|W) = (2,3,4,4,4,1,0,2,2)$
$r(x_{2,2}|W) = (2,3,4,4,4,1,2,0,2)$
$r(x_{3,2}|W) = (2,3,4,4,4,1,2,2,0)$
$r(x_{4,2}|W) = (2,3,4,4,4,1,2,2,2)$

Below is a figure of the graph $Amal(S_5, v, 2)$.

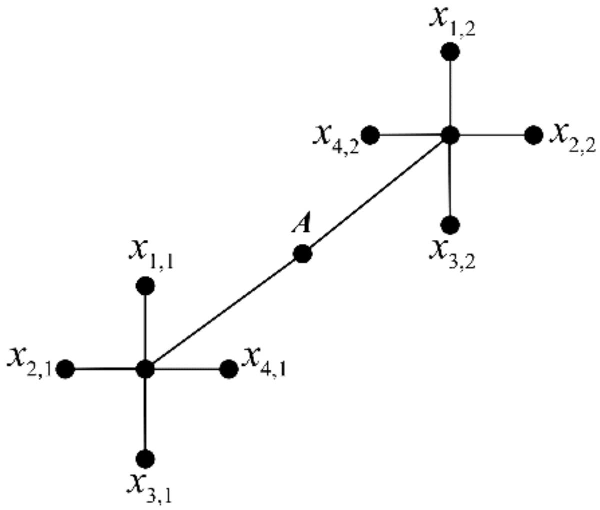

Figure 7. Graph $Amal(S_5, v, 2)$

3. Application of Star Metric Dimensions to Automatic Unmanned Aircraft in Fire Fields

The representation of each vertex is analogous to the coordinates of an airplane, while the base in the form of a star graph is likened to the control center of the aircraft and the location of the water source to prevent forest fires. Forests and land which are the object of research, namely South Sumatra Province, then the basis is obtained $Zs = \{13,14,15,16,17,18\}$, the number of coordinate points $|Zs| = 6, sdim = 6$.

$r(1|Zs) = (8,8,7,8,9,9)$
$r(2|Zs) = (7,7,6,7,8,8)$
$r(3|Zs) = (8,8,7,8,9,9)$
$r(4|Zs) = (9,9,8,9,10,10)$
$r(5|Zs) = (10,10,9,10,11,11)$
$r(6|Zs) = (3,3,2,3,4,4)$
$r(7|Zs) = (2,1,1,2,3,3)$
$r(8|Zs) = (2,2,1,1,2,3)$
$r(9|Zs) = (3,3,2,2,3,4)$
$r(10|Zs) = (4,4,3,3,4,5)$
$r(11|Zs) = (5,5,4,4,5,6)$
$r(12|Zs) = (6,6,5,5,6,7)$
$r(13|Zs) = (0,1,1,1,2,2)$
$r(14|Zs) = (1,0,2,1,1,2)$
$r(15|Zs) = (1,2,0,1,2,2)$
$r(16|Zs) = (1,1,1,0,1,1)$
$r(17|Zs) = (2,1,2,1,0,1)$
$r(18|Zs) = (2,2,2,1,1,0)$
$r(19|Zs) = (2,3,3,2,1)$
$r(20|Zs) = (2,1,2,3,3,2)$
$r(21|Zs) = (2,2,3,3,3,1)$
$r(22|Zs) = (2,3,3,3,2,1)$
$r(23|Zs) = (3,4,4,4,2,2)$
$r(24|Zs) = (4,4,5,5,3,3)$
$r(25|Zs) = (3,2,3,4,4,3)$
$r(26|Zs) = (4,3,4,5,5,4)$
$r(27|Zs) = (5,4,5,6,6,5)$
$r(28|Zs) = (5,5,6,6,5,4)$
$r(29|Zs) = (4,5,5,5,4,3)$
$r(30|Zs) = (3,4,4,4,3,2)$

The results of this study provide information about: can be in the form of input for forest fire prevention to local governments; increase knowledge in the field of graph theory, especially the study of metric dimensions; contribute to the development of new knowledge in the field of theory; develop other forms of graphs and apply them to certain cases related to the dimensional theory of star metrics.

D. CONCLUSION AND SUGGESTIONS

The following are the conclusions obtained from the results and the previous discussion: (1) the star graph's metric dimension value $Amal(L_m, v, n)$ is $sdim(Amal(L_m, v, n)) = 2n + 1$, with $m \geq 2$ and $n \geq 2$; (2) the star graph's metric dimension value $Amal(S_m, v, n)$ is

$sdim(Amal(S_m, v, n)) = 2n - 1$, with $m \geq 2$ and $n \geq 2$; (3) representation the graph of the area of Fire Forest Land is obtained basis $Zs = \{13,14,15,16,17,18\}$, the number of coordinate points $|Zs| = 6$, $sdim = 6$.

From the results of the research on metric dimensions, the researcher provides suggestions to other researchers so that they can examine the metric dimensions with other operating graphs. As well as being able to define applications related to metric dimensions to solve solutions in everyday life..

ACKNOWLEDGEMENT
The author would like to thank the University of Muhammadiyah Jember for providing the opportunity to conduct research and funding. Hopefully this is useful for the community.

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