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Network Connectivity Quality Assessment Case of Major Roads of Padangsidimpuan City

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ABSTRACT : Assessment of network connectivity in this study was done by using a special matrix operation. The quality of connectivity is measured based on network performance comparison value, between those of existing road network against those of expected road network. This network connectivity quality is derived into three aspects: number of connected nodes, total shortest path distance and total road length. The quality of the road network connectivity for the Truck Class 1 can be concluded as follows: The connectivity quality of the existing road network, in order to be equals to the expected road network needs an addition of 2 nodes: freight terminal 1 and freight terminal 2 and needs an addition of 1 ringroad and 2 access road, while warehouse in the existing road network must be abolished. The difference of total roads length between the existing network compared to the expected road network is 12.77 km, equal to a ratio of 0.76. Therefore, the existing road network requires an addition of 12.77 km in order to achieve the same quality as the expected road network. The total shortest path distance of the existing road network is infinite (∞) and the one of expected road network is 295.44 km.

Keywords: *network quality, connectivity, special matrix technique, assessment, distance, node*

1. INTRODUCTION

The quality of transport infrastructure, especially roads and terminals are very influential on the development of a city, since transportation plays an important role for the mobility of people and goods. Further more, this development will affect the improvement of economic development. The quality of the road must be assessed not only in terms quality of road segments and intersection, but also in terms of the overall network quality of the road network.

The research about the road network quality, especially the of connectivity quality in Padangsidimpuan city has never been done. Therefore, this research was conducted to assess how good or bad the road network quality in Padangsidimpuan cities at this time. In 2014 a research has been conducted to develop a quality assessment method for road network, where all the calculations were done using some special matrix operations and algebra min-plus matrix operations to calculate the shortest path. This method will be used in assessing the road network quality in Padangsidimpuan city. The reason for using this method because it is easy to used, it needs just Microsoft Excel software for calculations

(Suprayitno, 2014, Suprayitno, 2015) . Moreover, application of this method aims to introduce a new method that can be used as a reference for the analysis of the road network quality for those who want to do a study of the road network quality assessment.

This paper is focused on assessing the quality of the major road network connectivity in Padangsidimpuan city. Later on the connectivity quality value can be used to find a solution for quality improvement of road network connectivity in the future.

2. LITERATURE REVIEW

2.1 Network Model

The network model is composed of two elements: nodes and links (Suprayitno, 2014, Suprayitno, 2015) The nodes consist of three components: regional node, intersection and auxiliary node. While the link is the road segments. The network model is presented in the following Figure-1.

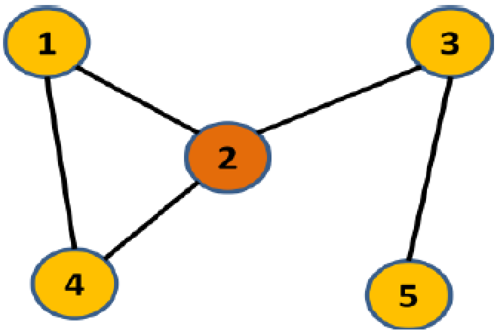

Figure 1. Network model

2.2 Special Matrix Technique

Quality of road network connectivity will be calculated by using special matrix in the form of a square matrix. Number of columns or rows indicates the number of nodes. This matrix technique needs three types of special matrix, i.e. basic matrix, expanded matrix and identification matrix (Suprayitno, 2014, Suprayitno, 2015). Three types of special matrix are presented in Table 1. below.

Table 1. Three Types of Special Matrix

Basic Matrix

BM	1	2	3	4
1				
2				
3				
4				

Expanded Matrix

EM	1	2	3	4	SR
1					
2					
3					
4					
SC					SM

Identification Matrix

EM	1	2	3	4	SR	IR
1						
2						
3						
4						
SC					SM	SIR
IC					SIC	

- **Expanded Matrix**

Expanded Matrix is always an expansion of a basic matrix, it contains: row, column and matrix summation (Suprayitno, 2014, Suprayitno, 2015). The summation formula is presented below.

$$m.E = m.B + SR_i + SC_j + SM \quad (1)$$

$$SR_i = \Sigma m_{ij}$$

$$SC_i = \Sigma m_{ij}$$

$$SM = \Sigma m_{ij} \text{ atau } \Sigma SR_j \text{ atau } \Sigma SC_i$$

- **Identification Matrix**

Identification Matrix, most of all is an expansion of an Expanded Matrix, to contain certain identification, based on Expanded Matrix Value, for certain characteristics of the network (Suprayitno, 2014, Suprayitno, 2015).

$$mei.I = m.E + IR_i + IC_j + SI \quad (2)$$

IR_i = for IR_i = *mathematical condition*, else C2

IC_j = C_1 for IC_j = *mathematical condition*, else C2

$$SIR = \Sigma IR_i$$

$$SIC = \Sigma IC_j$$

- **Distance**

  - **Direct Distance**

Direct distance between nodes is calculated using the following formula (Suprayitno, 2014):

$$m.D = \sqrt{mD^2} \quad (3)$$

$$m.D^2 = m.DX^2 + m.DY^2$$

$$m.DX^2 = m.DX * m.DX$$

$$m.DY^2 = m.DY * m.DY$$

$$m.DX = a.sumcX - a.sumrX$$

$$m.DY = a.sumcY - a.sumrY$$

Where:

m.D = The matrix of direct distance between nodes
$m.D^2$ = The square matrix of direct distance between nodes

$m.DX^2$ = The square matrix of the difference an abscissa x between nodes
$m.DY^2$ = The square matrix of the difference an abscissa y between nodes
m.DX = The matrix of the difference an abscissa x between nodes
m.DY = The matrix of the difference an abscissa y between nodes

- **Shortest Path**

The shortest path can be calculated using the Min-Plus Algebra (Suprayitno, 2014). The formulas are as follows. The M^{SP} is calculated by using the spreadsheet.

$$M^{SP} = M_{LL}{}^{\min\otimes(N-1)} \tag{4}$$

Where:

M^{SP} = The matrix of shortest path distance between node i to node j
M_{LL} = The matrix of link length
N = Number of nodes

Mechanism of matrix power Min-Plus algebra (Suprayitno, 2014) is as follows:

$$m^*_{ij} = \min(m_{i1}+m_{1n}, m_{i2}+m_{2n}, m_{i\ldots}+m_{\ldots n}, \ldots\ldots m_{in}+m_{nn}) \tag{5}$$

The following is an example of virtual network to calculate the matrix of shortest path distance. The network consists of 5 nodes connected by 8 links (Suprayitno, 2014) as presented in Figure 2. Using Microsoft Excel the matrix of shortest path calculation is show in the following Table 2.

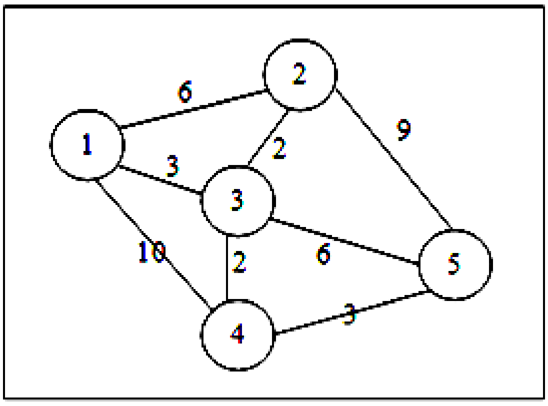

Figure 2. Virtual Network

Table 1. Calculation on M^{SP}

1	1	2	3	4	5
1	0	6	3	10	99
2	6	0	2	99	9
3	3	2	0	2	6
4	10	99	2	0	3
5	99	9	6	3	0

	1	2	3	4	5
1	0	6	3	10	99
2	6	0	2	99	9
3	3	2	0	2	6
4	10	99	2	0	3
5	99	9	6	3	0

2	1	2	3	4	5
1	0	5	3	5	9
2	5	0	2	4	8
3	3	2	0	2	5
4	5	4	2	0	3
5	9	8	5	3	0

3	1	2	3	4	5
1	0	5	3	5	8
2	5	0	2	4	7
3	3	2	0	2	5
4	5	4	2	0	3
5	8	7	5	3	0

4	1	2	3	4	5
1	0	5	3	5	8
2	5	0	2	4	7
3	3	2	0	2	5
4	5	4	2	0	3
5	8	7	5	3	0

2.3 Quality of Road Network

The quality of the road network can be derived into three components: quality of connectivity (connectivity and accessibility), quality of traffic flow and quality of coverage (Suprayitno, 2015). The model used is a very simple network consisting of lines (segments) and node (the center of regional activities, transportation terminals, junction or point geometry aids) (Suprayitno, 2014). Network quality components are represented in Table 3. below.

Table 2. Network Quality Components

Function	Quality item	Explanation
To connect different nodes of the region	Connectivity	How well the nodes are connected each other.
	Accessibility	How well a node can be accessed from the others and vice versa.
To flow the traffic	Traffic flow itenary	The itinerary quality for each pair of origin-destination.
	Traffic flow fluidity	The traffic flow performance: speed, delay, stops – traffic engineering.
To cover the region	Coverage	How well the region is covered.
	Density	How good is the network density part.

Source: Suprayitno, 2015

2.4 Connectivity Quality

The connectivity quality deals with how well the nodes are connected each other by road network (Suprayitno, 2014). Connectivity is important because an increasing of connectivity can decrease traffic on arterial streets, reduce travel time, create shorter travel distances and reduce the number of vehicle-kilometers travelled, provide continuous and more direct routes for travel by walking and biking, provide greater emergency vehicle access and reduced response time, provide improved utility connections, easier maintenance, and more efficient trash and recycling pick-up, lower speeds and reduce accident severity, better accommodate transit use (toolkit.valleyblueprint. org, 2015). Figure 3. and Figure 4. below shows the benefit of connectivity and efficiency of connectivity (Lehigh Valley Commission, 2011).

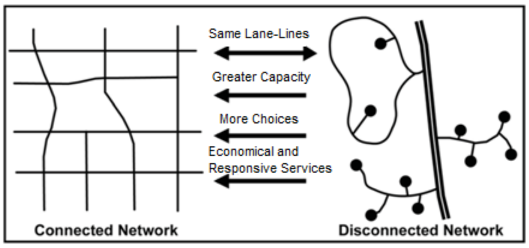

Figure-3 Benefit of connectivity

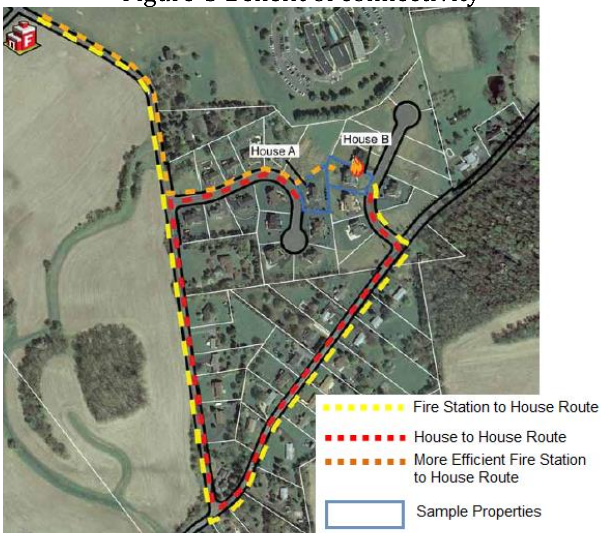

Figure 4. Efficiency of connectivity

The relative degree of connectedness within a transportation network (Information on webspace ship.edu, 2015) :

High connectivity = low isolation, high accessibility.

Low connectivity = high isolation, low accessibility.

Connectivity quality measures can be defined (Suprayitno,2014) as follows:

- Connectivity Quality in Terms of Number of Nodes Connected

This is a comparison between the number of nodes connected in the existing road network against the number of nodes connected in the expected road network. The formula is as follows:

$$CQ^N = \sum EXN^N / \sum EPN^N \quad (6)$$

Where:

CQ^N = connectivity quality in terms of nodes connected
ΣEXN^N = number of nodes connected by the existing network
ΣEPN^N = number of nodes connected by the expected network

- Connectivity Quality in Terms of Total Shortest Path Distance

The connectivity quality in terms of total shortest path distance will be calculated in two ways: first, total of the shortest path distance of the existing road network compared to the total direct distance of the existing network and second, the total shortest path distance of the existing network compared to the total shortest path distance of the expected road network.

- Compared to the direct distance, the formula is as follows:

$$CQ^{DD} = \sum EXN^{SP} / \sum EPN^{DD} \tag{7}$$

Where:

CQ^{DD}	=	connectivity quality types 1
ΣEXN^{SP}	=	total of the shortest paths distances between nodes
ΣEPN^{DD}	=	total of direct distance between nodes

- Compared to the expected networks, the formula is as follows:

$$CQ^{SP} = \sum EXN^{SP} / \sum EPN^{SP} \tag{8}$$

Figure 5. Road network Padangsidimpuan city

Figure 6. Road network will be reviewed

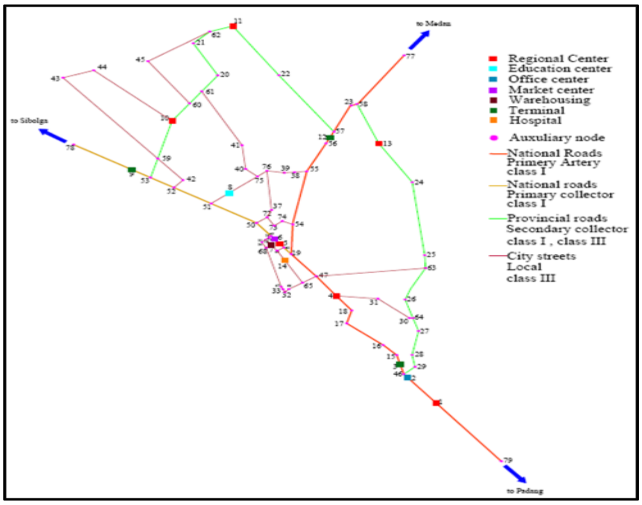

Figure 7. Road network model will be reviewed

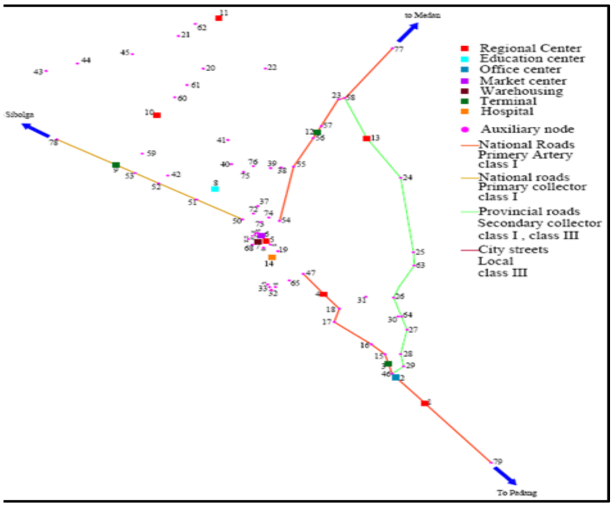

Figure 8. Existing Road network model for Truck Class 1

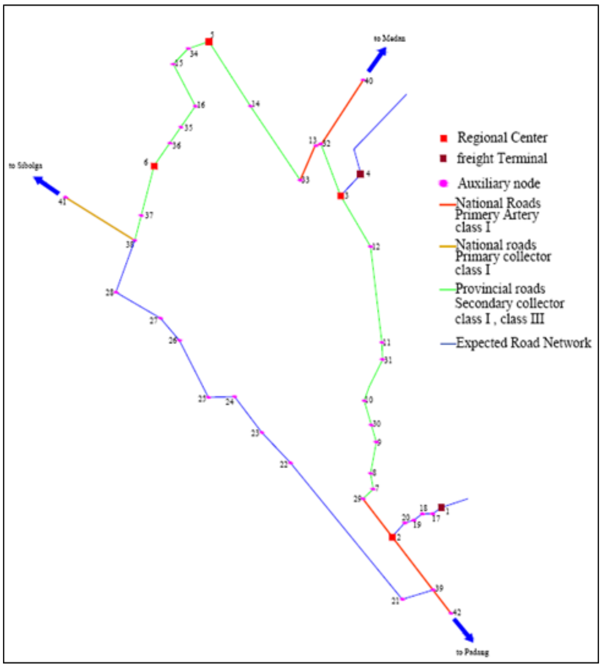

Figure 9. Expected road network model for Truck Class 1

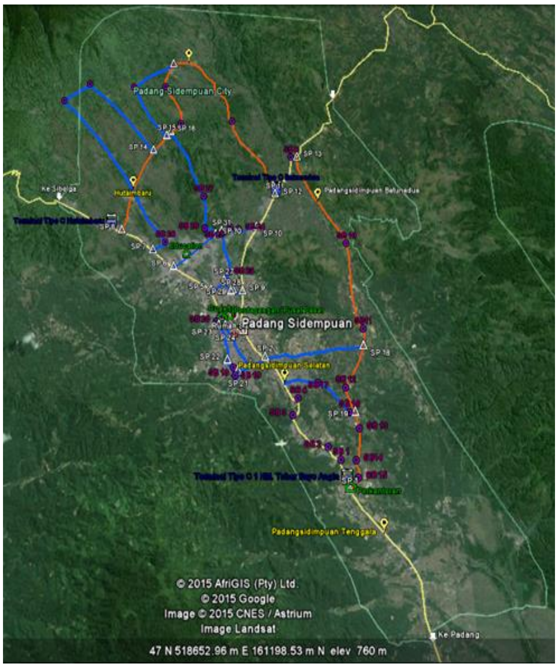

Figure 10. The nodes coordinate map

2.5 Data

Nodes Coordinate data are obtained from Google Earth. The coordinate data will be used to calculate the direct distance, as the first step of assessing the connectivity quality. The nodes coordinate of the existing road network and the expected road network are presented in Table 4. and Table 5. bellow:

Table 4. Nodes Coordinates of Existing Road Network

	No	Node	Coordinate x (m)	Coordinate y (m)	Coordinate x (km)	Coordinate y (km)	Description
Region Nodes	1	1	534527.81	146664.86	534.53	146.66	Southeast Padangsidimpuan Subdistrict
	2	2	533651.06	147660.03	533.65	147.66	Office Center
	3	3	533550.86	147885.90	533.55	147.89	HM.Tohar Bayo Angin Terminal (Type C)
	4	4	531809.63	150545.23	531.81	150.55	South Padangsidimpuan Subdistrict
	5	5	530117.25	152329.31	530.12	152.33	North Padangsidimpuan Subdistrict
	6	6	530127.64	152313.36	530.13	152.31	Market Center
	7	7	529927.37	152203.84	529.93	152.20	Warehousing
	8	8	528788.60	154147.05	528.79	154.15	Education Center
	9	9	526376.41	155046.59	526.38	155.05	Hutaimbaru Terminal (Type C)
	10	10	527015.43	156255.96	527.02	156.26	Padangsidimpuan Hutaimbaru Subdistrict
	11	11	528709.78	160578.97	528.71	160.58	Padangsidimpuan Angkola Julu Subdistrict
	12	12	531640.19	156150.15	531.64	156.15	Batunadua Terminal (Type C)
	13	13	532975.72	155908.48	532.98	155.91	Padangsidimpuan Batunadua Subdistrict
	14	14	530299.16	151715.00	530.30	151.72	Hospital
Auxiliary Nodes	15	15	533412.84	148456.74	533.41	148.46	Curve Segment 1
	16	16	533056.99	148793.09	533.06	148.79	Curve Segment 2
	17	17	532051.32	149615.58	532.05	149.62	Curve Segment 3
	18	18	532211.89	150076.37	532.21	150.08	Curve Segment 4
	19	19	530495.67	152088.37	530.50	152.09	Curve Segment 5
	20	20	528516.01	158393.10	528.52	158.39	Curve Segment 6
	21	21	527957.18	159626.86	527.96	159.63	Curve Segment 7
	22	22	530214.00	158498.39	530.21	158.50	Curve Segment 8
	23	23	532143.35	157283.14	532.14	157.28	Curve Segment 9
	24	24	533841.87	154558.94	533.84	154.56	Curve Segment 10
	25	25	534247.62	152031.94	534.25	152.03	Curve Segment 11
	26	26	533637.61	150381.94	533.64	150.38	Curve Segment 12
	27	27	533993.04	149287.00	533.99	149.29	Curve Segment 13
	28	28	533853.47	148452.13	533.85	148.45	Curve Segment 14
	29	29	533895.65	148001.12	533.90	148.00	Curve Segment 15
	30	30	533714.77	149717.27	533.71	149.72	Curve Segment 16
	31	31	532819.30	150518.41	532.82	150.52	Curve Segment 17
	32	32	530347.15	150707.94	530.35	150.71	Curve Segment 18
	33	33	530288.77	150923.71	530.29	150.92	Curve Segment 19
	34	34	529764.44	152202.22	529.76	152.20	Curve Segment 20
	35	35	529764.77	152214.64	529.76	152.21	Curve Segment 21
	36	36	529889.73	152391.50	529.89	152.39	Curve Segment 22
	37	37	530125.24	153682.15	530.13	153.68	Curve Segment 23
	38	38	530440.64	154996.95	530.44	155.00	Curve Segment 24
	39	39	530175.05	155058.16	530.18	155.06	Curve Segment 25
	40	40	529359.78	155012.50	529.36	155.01	Curve Segment 26
	41	41	529313.47	155994.41	529.31	155.99	Curve Segment 27
Auxiliary nodes	42	42	528120.27	154577.14	528.12	154.58	Curve Segment 28
	43	43	524612.03	159028.85	524.61	159.03	Curve Segment 29
	44	44	525428.48	159614.66	525.43	159.61	Curve Segment 30
	45	45	526895.59	159579.55	526.90	159.58	Curve Segment 31
	46	46	533625.24	147705.05	533.63	147.71	Intersection 1
	47	47	531237.29	151232.58	531.24	151.23	Intersection 2
	48	48	530172.13	152275.21	530.17	152.28	Intersection 3
	49	49	529977.45	152460.36	529.98	152.46	Intersection 4
	50	50	529576.86	153140.41	529.58	153.14	Intersection 5
	51	51	528394.46	153852.01	528.39	153.85	Intersection 6
	52	52	527728.79	154351.76	527.73	154.35	Intersection 7
	53	53	526712.80	154950.38	526.71	154.95	Intersection 8
	54	54	530555.80	153132.68	530.56	153.13	Intersection 9
	55	55	531000.80	155067.16	531.00	155.07	Intersection 10
	56	56	531605.65	156119.08	531.61	156.12	Intersection 11
	57	57	531665.73	156254.83	531.67	156.25	Intersection 12
	58	58	532338.18	157317.49	532.34	157.32	Intersection 13
	59	59	527627.29	157497.19	527.63	157.50	Intersection 14
	60	60	528042.91	157991.67	528.04	157.99	Intersection 15
	61	61	528174.48	158130.91	528.17	158.13	Intersection 16
	62	62	528200.42	160458.78	528.20	160.46	Intersection 17
	63	63	534224.56	151571.10	534.22	151.57	Intersection 18
	64	64	533883.68	149738.85	533.88	149.74	Intersection 19
	65	65	530794.32	151033.24	530.79	151.03	Intersection 20
	66	66	530419.76	150849.83	530.42	150.85	Intersection 21
	67	67	530100.73	151138.64	530.10	151.14	Intersection 22
	68	68	529833.57	152122.54	529.83	152.12	Intersection 23
	69	69	530028.89	152119.63	530.03	152.12	Intersection 24
	70	70	529813.77	152294.06	529.81	152.29	Intersection 25
	71	71	529891.80	152371.04	529.89	152.37	Intersection 26
	72	72	529977.12	153445.40	529.98	153.45	Intersection 27
	73	73	530194.67	153127.12	530.19	153.13	Intersection 28
	74	74	530254.11	153170.97	530.25	153.17	Intersection 29
	75	75	529700.25	154849.04	529.70	154.85	Intersection 30
	76	76	529886.98	154954.27	529.89	154.95	Intersection 31
	77	77	533578.23	159283.02	533.58	159.28	To Medan
	78	78	524666.49	155853.91	524.67	155.85	To Sibolga
	79	79	535684.17	144133.57	535.68	144.13	To Padang

Table 5. Nodes Coordinates of Expected Road Network

	No	Node	Coordinate x (m)	Coordinate y (m)	Coordinate x (km)	Coordinate y (km)	Description
Region Nodes	1	1	535879.69	146761.96	535.88	146.76	Freight Terminal 1
	2	2	534527.81	146664.86	534.53	146.66	Southeast Padangsidimpuan Subdistrict
	3	3	532975.72	155908.48	532.98	155.91	Padangsidimpuan Batunadua Subdistrict
	4	4	533424.38	156459.70	533.42	156.46	Freight terminal 2
	5	5	528709.78	160578.97	528.71	160.58	Padangsidimpuan Angkola Julu Subdistrict
	6	6	527015.43	156255.96	527.02	156.26	Padangsidimpuan Hutaimbaru Subdistrict
Auxiliary Nodes	7	7	533895.65	148001.12	533.90	148.00	Curve Segment 1
	8	8	533853.47	148452.13	533.85	148.45	Curve Segment 2
	9	9	533993.04	149287.00	533.99	149.29	Curve Segment 3
	10	10	533637.61	150381.94	533.64	150.38	Curve Segment 4
	11	11	534247.62	152031.94	534.25	152.03	Curve Segment 5
	12	12	533841.87	154558.94	533.84	154.56	Curve Segment 6
	13	13	532143.35	157283.14	532.14	157.28	Curve Segment 7
	14	14	530214.00	158498.39	530.21	158.50	Curve Segment 8
	15	15	527957.18	159626.86	527.96	159.63	Curve Segment 9
	16	16	528516.01	158393.10	528.52	158.39	Curve Segment 10
	17	17	535507.76	146724.99	535.51	146.72	Curve Segment 11
	18	18	535239.15	146858.28	535.24	146.86	Curve Segment 12
	19	19	535055.52	146863.48	535.06	146.86	Curve Segment 13
	20	20	534865.09	146900.83	534.87	146.90	Curve Segment 14
	21	21	534827.54	145215.82	534.83	145.22	Curve Segment 15
Auxiliary Nodes	22	22	530946.08	150132.01	530.95	150.13	Curve Segment 16
	23	23	530411.72	150294.36	530.41	150.29	Curve Segment 17
	24	24	529546.65	150562.07	529.55	150.56	Curve Segment 18
	25	25	527565.71	150688.58	527.57	150.69	Curve Segment 19
	26	26	527254.54	151968.62	527.25	151.97	Curve Segment 20
	27	27	527276.54	152701.00	527.28	152.70	Curve Segment 21
	28	28	526297.70	153747.96	526.30	153.75	Curve Segment 22
	29	29	533625.24	147705.05	533.63	147.71	Intersection 1
	30	30	533883.68	149738.85	533.88	149.74	Intersection 2
	31	31	534224.56	151571.10	534.22	151.57	Intersection 3
	32	32	532338.18	157317.49	532.34	157.32	Intersection 4
	33	33	531665.73	156254.83	531.67	156.25	Intersection 5
	34	34	528200.42	160458.78	528.20	160.46	Intersection 6
	35	35	528174.48	158130.91	528.17	158.13	Intersection 7
	36	36	528042.91	157991.67	528.04	157.99	Intersection 8
	37	37	527627.29	157497.19	527.63	157.50	Intersection 9
	38	38	526712.80	154950.38	526.71	154.95	Intersection 10
	39	39	535542.97	145162.84	535.54	145.16	Intersection 11
	40	40	533578.23	159283.02	533.58	159.28	To Medan
	41	41	524666.49	155853.91	524.67	155.85	To Sibolga
	42	42	535684.17	144133.57	535.68	144.13	To Padang

2.6 Calculation

The connectivity quality is measured based on performance comparison, between those of the existing road network against those of the expected road network. This connectivity quality is derived into three aspects: number of connected nodes, total shortest path distance and total road length.

- **Direct Distance Calculation**

The direct distance is an important variable in network connectivity quality assessment. Therefore the first step to be done is to calculate the direct distance between the nodes. The direct distance calculation is executed by using the Eq. 3. The result of direct distance calculation can be seen in Table 6. below.

Table 3. Matrix of Direct Distance

D(km)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	77	78	79	
1	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.97	6.40	9.91	24.28
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
77	0.00	0.00	0.00	0.00	0.00	0.00	7.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	9.55	15.30	32.81
78	0.00	0.00	0.00	0.00	0.00	0.00	6.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.55	**0.00**	16.09	32.04
79	0.00	0.00	0.00	0.00	0.00	0.00	9.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.30	16.09	**0.00**	41.29
	0.00	0.00	0.00	0.00	0.00	0.00	24.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.81	32.04	41.29	**130.42**

- **Road Segments Existence of The Existing Network for Truck Class 1**

The existence of road segments for truck class 1 is presented in binary numbers matrix. Number 1 means the segment exist, while the number 0 means no segments. Matrix of road segments existence will be used to calculate the total road length of the existing network. The existence of road segments for truck class 1 is presented in Table 7. below.

Table 4. Matrix of Road Segments Existence for Truck Class 1

		REGIONAL NODE														AUXILIARY NODE		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	77	78	79
REGIUONAL NODE	1	**0**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	2	1	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	1	0
	10	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0	0
AUXILIAR Y NODE	77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**	0	0
	78	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	**0**	0
	79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**

- **Roads Length Calculation for Truck Class 1 - The Existing Network**

Matrix of roads length for Truck Class 1 is obtained from matrix intersection of road segments existence for Truck Class 1 with a matrix of road length of all segments. The calculation is done by using the matrix extraction operation (Suprayitno,2014) as follows:

$$\mathrm{m.M} = \mathrm{m.X} \,\pi\, \mathrm{m.E} \quad (9)$$

$$\mathrm{m.M}_{i,j} = \mathrm{m.X}_{i,j} \forall\, \mathrm{m.E}_{i,j} \neq 0$$

where:

m.M = Matrix of roads length for Truck Class 1– The existing network

m.X = Matriks of roads length for all segments – The existing network

m.E = Matrix of Road Segments Existence for Truck Class 1

π = Extraction

∀ = If

The value of 99 indicate that the road length is infinite (∞), thus the nodes indicated are not connected, this gives indication that road network is not well connected. The calculation results can be seen in Table 8..

Table 5. Matrix of Roads Length for Truck Class 1 - The Existing Network

		REGIONAL NODE														AUXILIARY NODE			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	77	78	79	
REGIUONAL NODE	1	**0.00**	1.33	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	2.78	4.11
	2	1.33	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	1.38
	3	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.78
	4	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	1.51
	5	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	6	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	7	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	8	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	9	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	1.89	99.00	2.24
	10	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	11	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	0.00
	12	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	0.15
	13	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00	3.15
	14	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	0.00
AUXILIAR Y NODE	77	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	4.35
	78	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	1.89	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	3.57
	79	2.78	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	15.18
		4.11	1.38	0.78	1.51	0.00	0.00	0.00	0.00	2.24	0.00	0.00	0.15	3.15	0.00	4.35	3.57	15.18	79.55

- **Shortest Path Distance Calculation for Truck Class 1 - The Existing Network**

The shortest path distance is calculated by using Eq. 4 and Eq. 5. The result can be seen in matrix of the shortest path distance, presented in Table 9. below.

Table 6. Matrix of Shortest Path Distance for Truck Class 1- The Existing Network

78		REGIONAL NODE														AUXILIARY NODE		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	77	78	79
REGIUONAL NODE	1	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99	99	99
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00
AUXILIAR Y NODE	77	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	99	16.84
	78	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99	**0.00**	99
	79	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.84	99	**0.00**

- **Identification of Connected Nodes for Truck Class 1 - The Existing Network**

The number of nodes must be connected are four (4), nodes: 7, 77, 78, and 79. Identification of connected nodes can be obtained with this conditional: IR_j= 0 ∀ SR_j = 0, else= 1 and IC_i= 0 ∀ SC_i= 0, else= 1. Quality of nodes connected can be seen in Table 10. bellow.

Table 7. Identification Matrix of Connected Nodes for Truck Class 1 - The Existing Network

78		REGIONAL NODE														AUXILIARY NODE			SR	IR
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	77	78	79		
REGIUONAL NODE	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	7	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99	99	99	297.00	0
	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
AUXILIAR Y NODE	77	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	99	16.84	214.84	1
	78	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	99	**0.00**	99	297.00	0
	79	0.00	0.00	0.00	0.00	0.00	0.00	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.84	99	**0.00**	214.84	1
SC		0.00	0.00	0.00	0.00	0.00	0.00	297.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	214.84	297.00	214.84	1023.67	2
IC		0.00	0.00	0.00	0.00	0.00	0.00	594.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	429.67	594.00	429.67	2047.34	

- **Calculation for Truck Class 1 - The Expected Network**

Matrix of roads length, matrix of shortest path distance and identification matrix of connected nodes of the expected network for Truck Class 1 are calculated by the same way and the results are presented in Table 11., Table 12. and Table 13.

The connectivity quality of the road network for Truck Class 1 is presented in Table 14. below. Those were calculated by using Eq. 6 - Eq. 9

Table 8. Matrix of Roads Length for Truck Class 1 - The Expected Network

		REGIONAL NODE						AUXILIARY NODE		
		1	2	3	4	5	6	40	41	42
REGIONAL NODE	1	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00
	2	99.00	**0.00**	99.00	99.00	99.00	99.00	99.00	99.00	99.00
	3	99.00	99.00	**0.00**	0.71	99.00	99.00	99.00	99.00	99.00
	4	99.00	99.00	0.71	**0.00**	99.00	99.00	99.00	99.00	99.00
	5	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00	99.00
	6	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00	99.00
AUXILIARY NODE	40	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00	99.00
	41	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**	99.00
	42	99.00	99.00	99.00	99.00	99.00	99.00	99.00	99.00	**0.00**

Table 9. Matrix of Shortest Path Distance for Truck Class 1 - The Expected Network

41		REGIONAL NODE						AUXILIARY NODE			SR
		1	2	3	4	5	6	40	41	42	
REGIONAL NODE	1	**0.00**	0.00	0.00	12.36	0.00	0.00	15.52	20.70	4.31	52.88
	2	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4	12.36	0.00	0.00	**0.00**	0.00	0.00	4.58	20.54	13.74	51.22
	5	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00
AUXILIARY NODE	40	15.52	0.00	0.00	4.58	0.00	0.00	0.00	20.61	16.90	57.61
	41	20.70	0.00	0.00	20.54	0.00	0.00	20.61	0.00	18.46	80.30
	42	4.31	0.00	0.00	13.74	0.00	0.00	16.90	18.46	0.00	53.42
SC		52.88	0.00	0.00	51.22	0.00	0.00	57.61	80.30	53.42	**295.44**

Table 10. Identification Matrix of Connected Nodes for Truck Class 1 – The Expected Network

41		REGIONAL NODE						AUXILIARY NODE			SR	IR
		1	2	3	4	5	6	40	41	42		
REGIONAL NODE	1	**0.00**	0.00	0.00	12.36	0.00	0.00	15.52	20.70	4.31	52.88	1
	2	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	3	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	4	12.36	0.00	0.00	**0.00**	0.00	0.00	4.58	20.54	13.74	51.22	1
	5	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0
	6	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0
AUXILIARY NODE	40	15.52	0.00	0.00	4.58	0.00	0.00	0.00	20.61	16.90	57.61	1
	41	20.70	0.00	0.00	20.54	0.00	0.00	20.61	0.00	18.46	80.30	1
	42	4.31	0.00	0.00	13.74	0.00	0.00	16.90	18.46	0.00	53.42	1
SC		52.88	0.00	0.00	51.22	0.00	0.00	57.61	80.30	53.42	**295.44**	5
IC		1	0	0	1	0	0	1	1	1	5	

Result

3. CONCLUSIONS

The quality of the road network connectivity for Truck Class 1can be concluded as follows:

Number of nodes connected for the existing road network are 2 nodes, while those for the expected road network are 5 nodes. The ratio then is 0.5. The expected road network has 5 nodes which should be connected, because the warehouse in existing road network must be displaced and added by 2 new freight terminals. The connectivity quality of the existing road network in order to be equals to the connectivity quality of the expected road network then, it needs an addition of 2 nodes: freight terminal 1 and freight terminal 2, while the warehouse (node ID 7) in the existing road network is abolished. Then, those nodes must be connected each other by new road network.

Table 11. Connectivity Quality of Road Network for Truck Class 1

Quality Aspect			Value		Ratio	
Nodes connected	existing	Number of nodes need to be connected	4	node	50 %	50/100= 0.5
		Number of nodes connected	2	node		
		Number of nodes unconnected	2	node		
	expected	Number of nodes need to be connected	5	node	100%	
		Number of nodes connected	5	node		
		Number of nodes unconnected	0	node		
Shortest path distance	existing	Total of shortest path distance	∞	km		∞/295.44= ∞
	expected		295.44	km		
	direct distance		130.42	km		∞/130.42 = ∞
Roads length	existing	Total of roads length	39.77	km		39.77/52.54= 0.76 Δ= 52.54 - 39.77= 12.77 km
	expected		52.54	km		

The shortest path distance of the existing road network is infinite (∞). It means there are certain nodes which are unconnected. The shortest path distance for the expected road network is 295.44 km. The ratio is then ∞. In order to achieve the expected road network quality it needs 2 addition of nodes and all must be connected each other by road network.

Total roads length of the existing road network and the expected road network are 39.77 km and 52.54 km respectively, with a difference of 12.77 km and a ratio of 0.76. Therefore, the existing road network requires an addition of 12.77 km in order to achieve the same quality as the expected road network.

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