Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 77 - 90, 2005

Finding Dominant Links of Emergency Network with Respect to Earthquake Disaster

Penghsi HOU
Ph.D. Candidate
Institute of Traffic and Transportation
National Chiaotung University
4F, 114 Chung Hsiao W. Rd., Sec. 1, Taipei, 100-12 Taiwan (ROC)
Fax: +886-2-2349-4953
E-mail: journal.9036801@nctu.edu.tw

Yuanching HSU
Professor
Institute of Traffic and Transportation
National Chiaotung University
4F, 114 Chung Hsiao W. Rd., Sec. 1, Taipei, 100-12 Taiwan (ROC)
Fax: +886-2-2349-4953
E-mail: ychsu@mail.nctu.edu.tw

Abstract: Transportation is one of the most important functions that a network provides. However, those functions may fail due to ruined links caused by earthquake disasters. We took emergency paths as our strategies to connect demand and supply nodes. The used links under various replaceable paths were considered factors causing the job to succeed. We used passed probability as index to represent the ability of every link. When the probabilities of some links are relatively higher, they are claimed dominant links. Enumeration algorithm was used to calculate the probability of every link. With respect to three activities: fire rescue, medical rescue, and logistics supply, we can identify the essence of every link. At the final part, the network of Lingya administrative district of Kaohsiung City in Taiwan was taken as an example to apply this method. We have found 17 fire rescue, 19 medical rescue, and 17 logistics supply dominant links.

Key Words: dominant link, emergency path, emergency network, earthquake, disaster

1. INTRODUCTION

The planning of road network is one of the most important parts of disaster prevention system. Road network is an essential interface that makes many activities accomplished successfully. However, few road networks are constructed with respect of disaster prevention in Taiwan. There is considerable risk in using road network after disaster, since we have no idea whether these links are still workable giving the possibility of being ruined by disaster, either directly or indirectly. The paper shows a new index to determine dominant links in a road network in case of an emergency such as an earthquake. In this paper, we intend to find out which links are relatively worth being improved. We use probability concept to establish the index to show that some links are repeatedly used. The index shows the passed probabilities of links with respect to emergency activities of fire rescue, medical rescue, and logistics supply. If we can identify critical links that are used more frequently or being passed by many times, we can prioritize our prevention focus to maintain these dominant links to be accessible. Thus, the connections of most of supply and demand units in the road network system can be better assured. By better dominant links, the road network system would be operated more efficient for transportation or emergency activities.

2. ANALYTICAL FRAMEWORK

Emergency path after earthquake disaster are paths connecting special nodes for certain emergency tasks, such as the shortest time to reach a firing place for fire engines, or to reach injured people for the ambulance. These special nodes include both supply nodes such as fire stations or hospitals, and demand nodes such as residential houses.

An emergency path provides many functions. From the earthquake experiences in Japan and Taiwan, there are at least three important activities proceeding after earthquakes: fire rescue, medical rescue, and logistics supply (Hou, 2002). These activities proceed in different periods of time (Ho and Lee, 1998).

What is the characteristic of emergency paths in a road network? Road network provides services for general transportation. The emergency paths deal with easygoing affairs. During earthquake disaster, emergency paths can provide critical functions such as the three core activities, rather than just regular daily function. Therefore, these emergency paths need to be maintained in working condition, especially during disasters, to keep important connections for the core activities.

The framework of this study is first to discuss the concepts of road network scales and dominant links. Secondly, it is to analyze link node relationships and to develop an enumeration algorithm. We adopted GIS procedure, and converted supply and demand units into workable nodes that can be calculated and analyzed in the network system. The establishment of a probability index can be used to represent the frequency that a link might be used under the emergency activities. Dominant links can then be found. A case study is presented in this paper to illustrate finding dominant links of its network system.

3. CONCEPTS OF ROAD NETWORK SCALES AND DOMINANT LINKS

(1) Replaceable path and network

In a road network system, suppose one primary path connects a demand node D and a supply node S. Then another path is called a replaceable path where it connects D and S as well but contains different link(s) from the primary one. The network system is called replaceable network where it contains replaceable paths. Replaceable network is an important concept for disaster prevention because it provides accessibility between demand and supply nodes during disaster while the primary paths fail.

(2) Road network scale

According to the concept of replaceable network, we classify three scales of road network for disaster prevention: primary scale, secondary scale, and tertiary scale. They are sequentially illustrated in Figure 1 and described more specifically below.

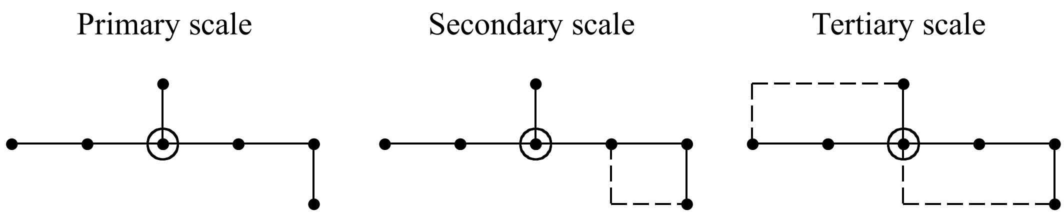


Figure 1. Road Network Scales

A. Primary scale

Road network of primary scale provides rapid and comprehensive connections among all supply and demand nodes (Hou, 2002). It is similar to a shortest path tree and hence does not contain replaceable paths. This is the basic prototype road network for disaster prevention, focusing on paths of time efficiency. Briefly speaking, this primary network for disaster prevention spans among nodes without replaceable paths, and hence is not replaceable network. However, it costs less as consequence.

B. Secondary scale

Secondary scale network extends primary scale network. It contains extra links of replaceable paths for some primary paths in the primary scale network, but not for all of them. This means that if some link of the primary scale were ruined by earthquake disaster, there would be opportunities to connect demand and supply nodes through these additional links.

C. Tertiary scale

Tertiary scale network is based on primary scale network. More over it guarantees that if any link of the primary scale is ruined by disaster, there will be another path(s) to connect the original two nodes. This means that any pair of demand and supply nodes has at least one replaceable path for its primary one.

(3) Dominant link

From the concept of road network scale, we are interested in finding link(s) that control most of the replaceable paths. Suppose that all factors affecting the path choices are equal, i.e. chances of a path being selected are the same. The links with high passed frequency among all replaceable paths are called dominant links. If these dominant links were ruined, the road network would reduce many possible replaceable paths. In this article we set passed probability of 0.5 as a value to distinguish dominant links. This means that these dominant links can control more than half possible replaceable paths.

Figure 2 illustrates how we get the probability of each link. Suppose that we have 2 demand nodes v_1, v_4 and only one supply node v_s (v_8). The simplest way to know how the links are possibly used is to list all possible paths. There are 10 possible paths between the demand node v_1 and the supply node v_8, and 8 possible paths between v_4 and v_8 in this example. We can then record the times of each link used under the possible ways and calculate to the passed probabilities as shown in Table 1. The passed probability of links is calculated in the way as Equation 1 below.

$$P_a(e_i) = \frac{n_{a,e_i}}{n_{a,p}} \qquad \text{(1)}$$

a: activity a containing all paths situations from demand node set to supply node set

$P_a(e_i)$: passed probability of link e_i under activity a

n_{a,e_i}: the passed times of link e_i under activity a

$n_{a,p}$: the total number of replaceable paths under activity a

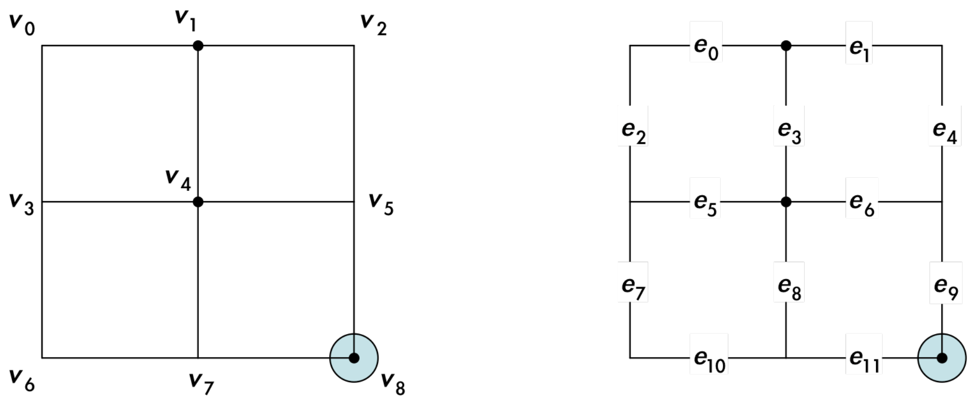


Figure 2. An Illustration of Finding Dominant Links

Table 1. Passed Probabilities of Links in an Example

D > S (Path No.)	Path \ Link label	e_0	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	e_{10}	e_{11}
		passed times / passed probability											
1 > 8 (10)	0: 1 > 2 > 5 > 8 1: 1 > 2 > 5 > 4 > 7 > 8 2: 1 > 2 > 5 > 4 > 3 > 6 > 7 > 8 3: 1 > 4 > 5 > 8 4: 1 > 4 > 7 > 8 5: 1 > 4 > 3 > 6 > 7 > 8 6: 1 > 0 > 3 > 4 > 5 > 8 7: 1 > 0 > 3 > 4 > 7 > 8 8: 1 > 0 > 3 > 6 > 7 > 4 > 5 > 8 9: 1 > 0 > 3 > 6 > 7 > 8	4 / .400	3 / .300	4 / .400	3 / .300	3 / .300	4 / .400	5 / .500	4 / .400	4 / .400	4 / .400	4 / .400	6 / .600
5 > 8 (8)	0: 5 > 2 > 1 > 4 > 7 > 8 1: 5 > 2 > 1 > 4 > 3 > 6 > 7 > 8 2: 5 > 2 > 1 > 0 > 3 > 4 > 7 > 8 3: 5 > 2 > 1 > 0 > 3 > 6 > 7 > 8 4: 5 > 8 5: 5 > 4 > 1 > 0 > 3 > 6 > 7 > 8 6: 5 > 4 > 7 > 8 7: 5 > 4 > 3 > 6 > 7 > 8	3 / .375	4 / .500	3 / .375	3 / .375	4 / .500	3 / .375	3 / .375	4 / .500	3 / .375	1 / .125	4 / .500	7 / .875
Network (18)		7 / .389	7 / .389	7 / .389	6 / .333	7 / .389	7 / .389	8 / .444	8 / .444	7 / .389	5 / .278	8 / .444	13 / .722

We notice that link e_{11} has the highest passed times and therefore the highest passed probability. Hence, link e_{11} with passed probability of 0.722 over 0.5 is deemed dominant link in this example. That means link e_{11} controls more than half replaceable paths between demand and supply nodes in this network system.

4. LINK NODE RELATIONSHIPS AND ENUMERATION ALGORITHM

Before we formally start to find out the dominant links, we are going to introduce the relationships between links and nodes of network.

(1) Link

Link is one of the basic elements composing a network. And link weight is the most important attribute. In most of time, link weight is expressed by cost concepts, such as travel time cost, distance cost, etc. For the purpose of getting timely transportation, we selected travel time cost as the link weight to construct the network for disaster prevention. We used the relationship between lane width and driving speed to transform adequate travel speed (Gunay, 1999). With collected length data of links and the transformed travel speed on every link, we therefore get travel time cost in second unit of every link.

(2) Node

Node is another basic element of network. Before deciding a path, we need to know where to start and where to end. With respect to disaster prevention, we classify two groups of nodes: supply nodes and demand nodes. It is easier to figure out the supply nodes because they are specific places, such as fire stations, hospitals, etc. However, demand nodes are more difficult to identify. Suppose that people are the target for rescue. They may be either on the road or scattered in a residential area. In short, these “demand nodes” such as people are at undefined positions. In this case, we can settle down these potential demands into nodes to construct the network. Taking minimal unit of administrative district as the demand node base, and applying the GIS software, these districts (polygon type) can be transformed into mass centers of nodes (point type) according to their geometric positions (Delaune, 1990).

(3) Link-node relationship

A. Adjacency matrix

Adjacency matrix represents relationship among nodes in a network (West, 2001). First, we identified the node with highest degree m, i.e. connecting m adjacent nodes in the network system. Suppose we have n nodes in a network, we can get a matrix of m rows and n columns that represent the relationships among each node. We give certain value, such as –1, into the matrix to represent a dummy node, for those nodes that have less than m adjacent nodes. As illustrated in Figure 3, node 4 has four adjacent nodes, which has the most in the network. We set m to be four rows for adjacency matrix and assume each node has up to four adjacent nodes. Node 4 has node 1, 5, 7 and 3 adjacent to it. We put $[1, 5, 7, 3]^t$ into node 4 column to show the adjacent relationship of node 4. However, node 0, 2, 6, 8 have only two adjacent nodes. Therefore we need to assign two invisible dummy nodes labeled “-1” for them. Node 1, 3, 5, 7 have three adjacent nodes, and we need to assign one dummy node for them as well.

	Node Label								
	0	1	2	3	4	5	6	7	8
Direction	-1	-1	-1	0	1	2	3	4	5
	1	2	-1	4	5	-1	7	8	-1
	3	4	5	6	7	8	-1	-1	-1
	-1	0	1	-1	3	4	-1	6	7

Adjacency Matrix

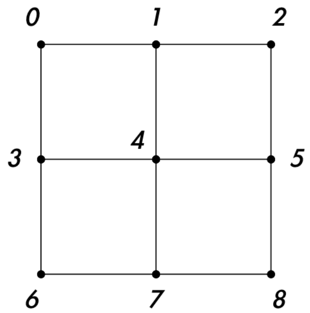
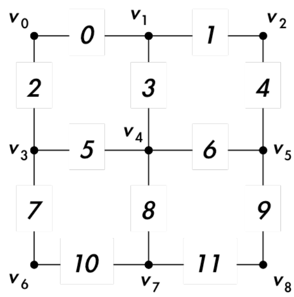


Figure 3. An Example of Adjacency Matrix

B. Incidence matrix

Incidence matrix represents relationship among nodes and links in a network (West, 2001). Suppose we have n nodes in a network, and we get a matrix of n rows and n columns to represent the relationship between each node and its links. We put certain value, such as –1, into the matrix to represent dummy links that are not incident. For incident links, we put the number to represent the relationship between the node and the link. For example, the node 4 in Figure 3 has four incident links in Figure 4. Then we put [–1, 3, -1, 5, -1, 6, -1, 8, -1] into the row of node 4. Because node 0, 2, 4, 6, 8 are not adjacent to it, we assigned invisible dummy incident links labeled “–1” for node 4.

Node Label	0	1	2	3	4	5	6	7	8
0	-1	0	-1	2	-1	-1	-1	-1	-1
1	0	-1	1	-1	3	-1	-1	-1	-1
2	-1	1	-1	-1	-1	4	-1	-1	-1
3	2	-1	-1	-1	5	-1	7	-1	-1
4	-1	3	-1	5	-1	6	-1	8	-1
5	-1	-1	4	-1	6	-1	-1	-1	9
6	-1	-1	-1	7	-1	-1	-1	10	-1
7	-1	-1	-1	-1	8	-1	10	-1	11
8	-1	-1	-1	-1	-1	9	-1	11	-1



Incidence Matrix

Figure 4. An Example of Incidence Matrix

(4) Enumeration algorithm

Our iteration of the enumeration algorithm consists of several steps. The first step is to identify where the demand and supply nodes located and to identify the configuration of the network system. Suppose we assign one demand node and one supply node from the node sets to compose a demand-supply node pair. We use a node recorder to record the node sequence to represent the paths.

The second step is to traverse the whole network by moving the present node. The objective is to find all replaceable paths between the demand and supply nodes. If all nodes were traversed (visited), all possible paths had been exhausted. Then another new demand-supply node will be selected, and the procedure will be repeated until all pairs are explored. Then we can calculate the passed times of each link, and obtain dominant links according to a designated probability level.

Under the structures of adjacency matrix of nodes relationship and incidence matrix of link-node relationship, the deep-first-search (Cormen et al., 2001) to traverse all of the nodes will be applied. Every adjacent node of the present node will be checked. If the unvisited adjacent nodes exist and were not in the recorder, then the present node will go deeper until reaching the end node (supply node). If these unvisited nodes do not exist or are already in the recorder, then the present node will go back to the predecessor node according to the sequence in the recorder, and the procedure will be repeated again. As the result, the path set of all of demand-supply node pair can be obtained, as well as the passed times of links. The operation flow of this enumeration algorithm is illustrated in Figure 5.

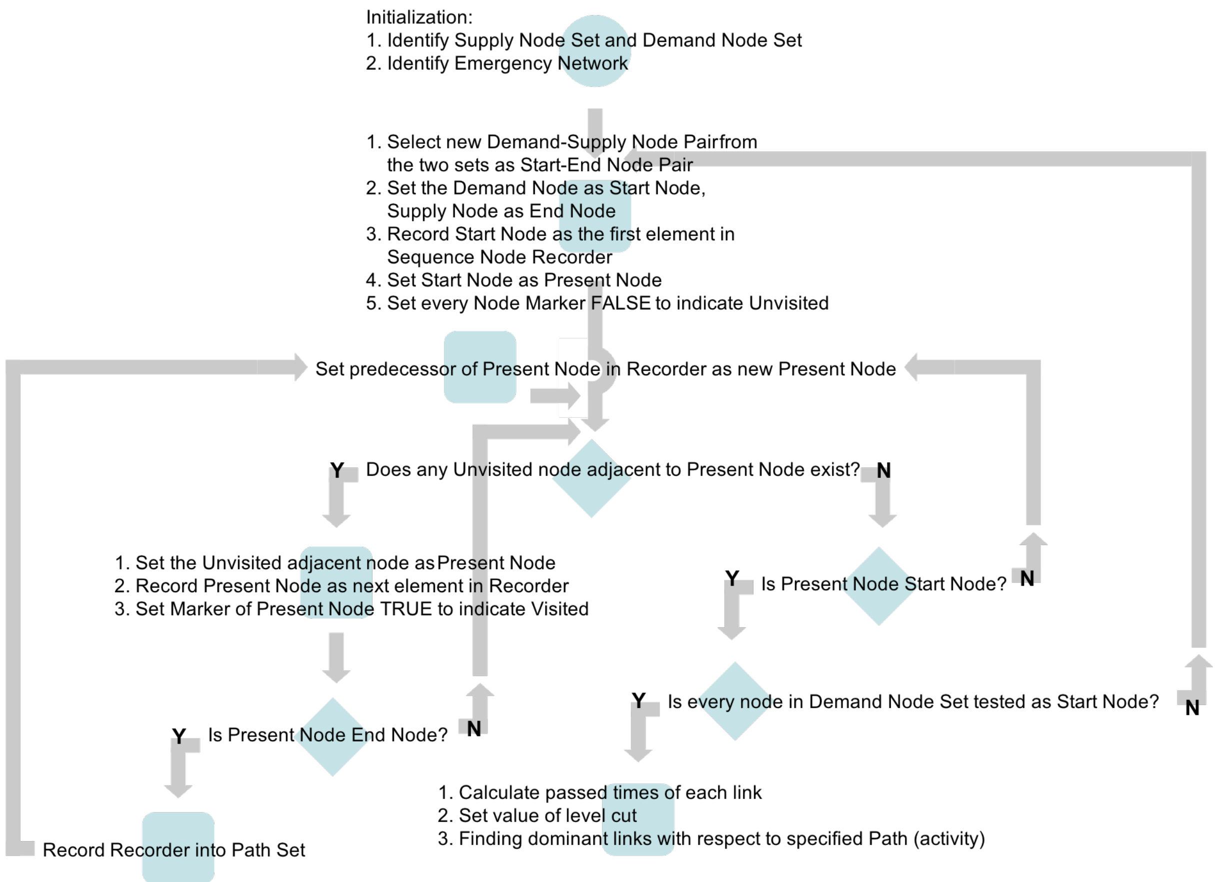


Figure 5. Flowchart of Enumeration Algorithm

5. CASE STUDY IN TAIWAN

(1) Background

Kaohsiung city is the largest city of south Taiwan. We take the geographically central district, Lingya district, where also Koahsiung municipal government is located, as our case to plan the road network for disaster prevention (Figure 6).

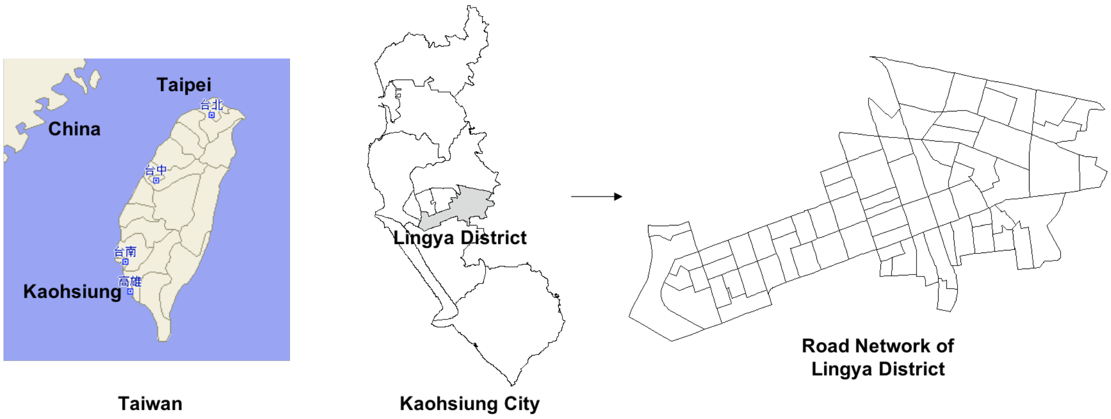


Figure 6. Study Area Lingya District in Kaohsiung, Taiwan

In Lingya, there are 201,180 residents that consisted of the 69 administrative segments with an average population of 2,900 (Civil Affairs Bureau, 2001). The open spaces are classified by 10,000 m^2, suggested as an adequate space for safe evacuation (Lee and Qian, 1999). There are 13 elementary and junior high schools, 8 hospitals, and one fire station. The total length of the road network with width over 8 meters, which is classified adequate for emergency evacuation (Lee and Qian, 1999), is 87.6 kilometers.

Table 2. Background Data of Lingya District

System for disaster prevention	Class	Number
Demand nodes of disaster prevention	People	69
	Open space less than 10000m^2	12
	Open space over 10000m^2	11
	School	13
Supply nodes of disaster prevention	Fire station	1
	Hospital	8
	Harbor, airport	0
Road network	Road width over 8m	87.6 km

(2) Selection of road network base for disaster prevention

First, we select basic road network according to road width wider than 8 meters. Second, optimum routing developed in ArcView Network Analyst (ESRI, 1992) helps to construct a network that connects all the supply nodes and demand nodes with respect to fire rescue, medical rescue, and logistics supply. Hence, we get three basic road networks according to these emergency activities. And finally we unite the three basic networks into one. Consequently, we get a network like Figure 7 and Figure 8. The question now is which links will affect the network most significantly if broken. Whether a link ruined by earthquake will affect more than half possible replaceable paths? It is hard to figure out just by looking at the road network map. Hence, we suggested the method mentioned previously to answer the question.

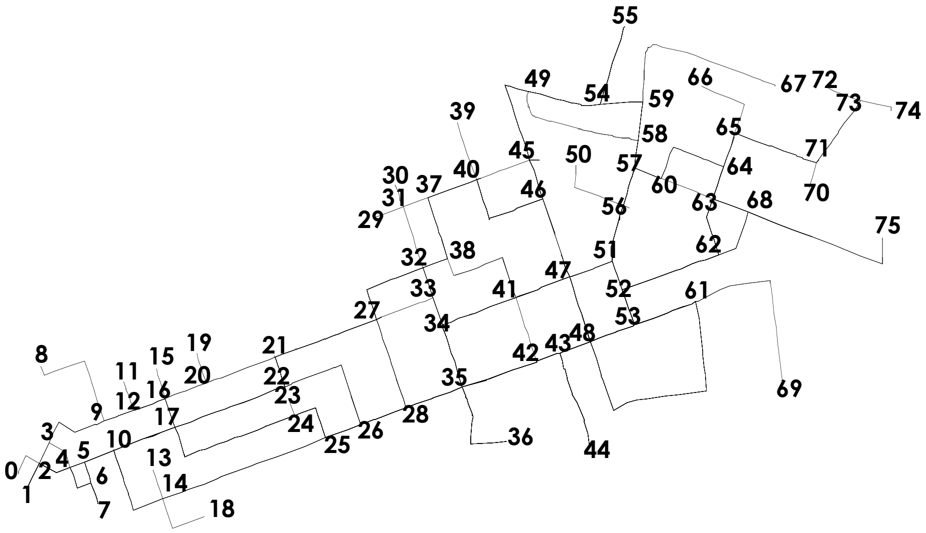


Figure 7. Labeling Nodes of Road Network in Lingya District

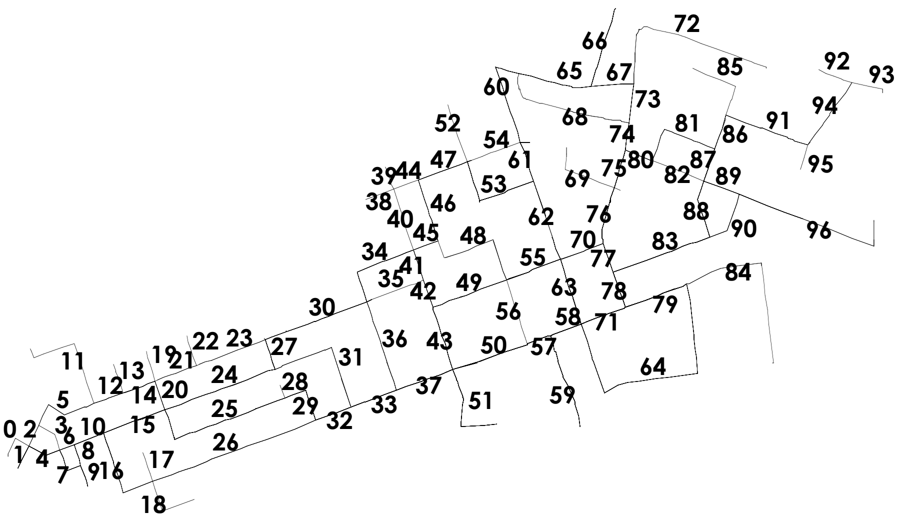


Figure 8. Labeling Links of Road Network in Lingya District

(3) Link probabilities from enumeration algorithm

First, we labeled each link and node with unique number from 0. We therefore got 76 nodes from number 0 to 75 like Figure 6, and 97 links from number 0 to 96 like Figure 7. Using Java technology J2SDK 1.4.2 (Sun, 2003) implementing the steps of the enumeration algorithm, we assign a demand node and a supply node in order to get the passed times of each link. And assign another node pair of demand node and supply node to get another result, and so on. After all possible compositions were done, we added the passed times of each link together and divided it by the total number of all possible emergency paths to get the passed probabilities of each link.

The previous enumeration procedure will be applied in the followings on the tree important emergency activities, including fire rescue, medical rescue, and logistics supply. We individually identify the demand and supply nodes according to the features of the activity. In fire rescue activity, residential areas will be taken as the demand areas, and the fire station as the supply unit. In medical rescue activity, hospitals will be supply units where open spaces and schools taken as demand units. Entries of road into this district in logistics supply activity will be supply nodes by logistics vehicles from other district areas, and the open spaces and schools are rendered as demand nodes. Replaceable paths of these activities will be found through the enumeration algorithm. We can obtain passed times and passed probabilities of each link under these replaceable paths. And according to a designated probability level, dominant links can be identified.

A. Fire rescue:

With respect to fire rescue, we used residential population as one part of demand nodes. With Xtools Extension (Delaune, 1990), the polygons of residential district can be converted to points according to the positions of centroids of the polygons. The population attribute in that polygons is also contained in that centroid points. We took temporary refuges, i.e. open spaces less than 10000m^2 (Ho and Lee, 1998), as the other part of demand nodes. The fire station is used as supply node. Input all the compositions of supply node and demand nodes in the enumeration algorithm. Setting 0.5 of probability as a limit of dominant links, we got the following result. Links of number 5, 10, 12, 14, 21, 23, 30, 32, 33, 37, 47, 50, 60, 74, 79, 80, and 83 are dominant links with respect to fire rescue.

Table 3. Passed Probabilities of Links with Respect to Fire Rescue

e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$
0	0.022	20	0.283	40	0.414	60	0.766	80	0.696
1	0.000	21	0.598	41	0.447	61	0.461	81	0.387
2	0.360	22	0.000	42	0.342	62	0.341	82	0.387
3	0.360	23	0.584	43	0.372	63	0.327	83	0.693
4	0.360	24	0.478	44	0.409	64	0.433	84	0.022
5	0.689	25	0.375	45	0.410	65	0.390	85	0.022
6	0.361	26	0.480	46	0.472	66	0.000	86	0.111
7	0.361	27	0.321	47	0.715	67	0.390	87	0.387
8	0.361	28	0.022	48	0.359	68	0.390	88	0.362
9	0.022	29	0.372	49	0.438	69	0.022	89	0.362
10	0.708	30	0.727	50	0.505	70	0.452	90	0.362
11	0.022	31	0.392	51	0.022	71	0.411	91	0.089
12	0.674	32	0.522	52	0.022	72	0.022	92	0.022
13	0.022	33	0.776	53	0.444	73	0.390	93	0.022
14	0.644	34	0.405	54	0.444	74	0.757	94	0.044
15	0.351	35	0.456	55	0.406	75	0.320	95	0.022
16	0.493	36	0.185	56	0.359	76	0.339	96	0.022
17	0.022	37	0.729	57	0.463	77	0.424		
18	0.000	38	0.022	58	0.445	78	0.497		
19	0.000	39	0.000	59	0.022	79	0.545		

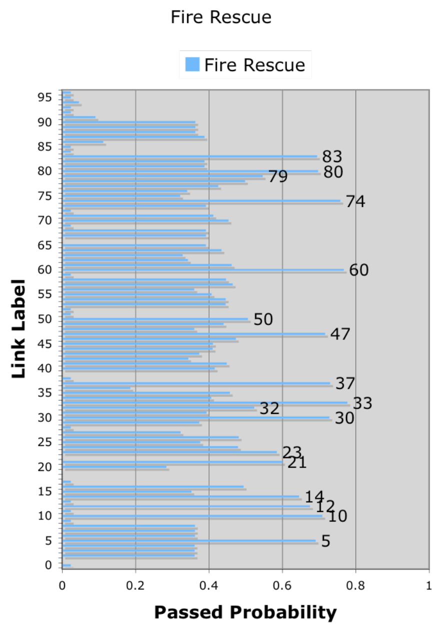


Figure 9. Dominant Fire Rescue Links

B. Medical rescue:

With respect to medical rescue, we used residential population gathered in open spaces over 10000m^2 and schools as the demand nodes. The hospitals are used as supply node. Input all the compositions of supply node and demand nodes in the enumeration algorithm. Setting 0.5 of probability as a limit of dominant links, we get the following result. Links of number 5, 10, 12, 14, 21, 23, 30, 32, 33, 37, 47, 50, 57, 58, 60, 74, 78, 80, and 83 are dominant links with respect to medical rescue.

Table 4. Passed Probabilities of Links with Respect to Medical Rescue

e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$
0	0.000	20	0.234	40	0.403	60	0.718	80	0.670
1	0.000	21	0.603	41	0.437	61	0.437	81	0.357
2	0.333	22	0.000	42	0.245	62	0.292	82	0.350
3	0.333	23	0.603	43	0.300	63	0.235	83	0.688
4	0.333	24	0.464	44	0.403	64	0.356	84	0.000
5	0.666	25	0.325	45	0.407	65	0.351	85	0.000
6	0.312	26	0.425	46	0.448	66	0.000	86	0.085
7	0.354	27	0.237	47	0.687	67	0.351	87	0.350
8	0.312	28	0.000	48	0.291	68	0.351	88	0.325
9	0.085	29	0.325	49	0.467	69	0.000	89	0.347
10	0.586	30	0.782	50	0.548	70	0.308	90	0.332
11	0.000	31	0.327	51	0.021	71	0.356	91	0.000
12	0.666	32	0.510	52	0.000	72	0.000	92	0.000
13	0.000	33	0.796	53	0.418	73	0.351	93	0.000
14	0.666	34	0.431	54	0.402	74	0.702	94	0.000
15	0.303	35	0.476	55	0.353	75	0.265	95	0.000
16	0.425	36	0.073	56	0.318	76	0.273	96	0.064
17	0.000	37	0.792	57	0.655	77	0.309		
18	0.000	38	0.000	58	0.667	78	0.694		
19	0.000	39	0.000	59	0.021	79	0.356		

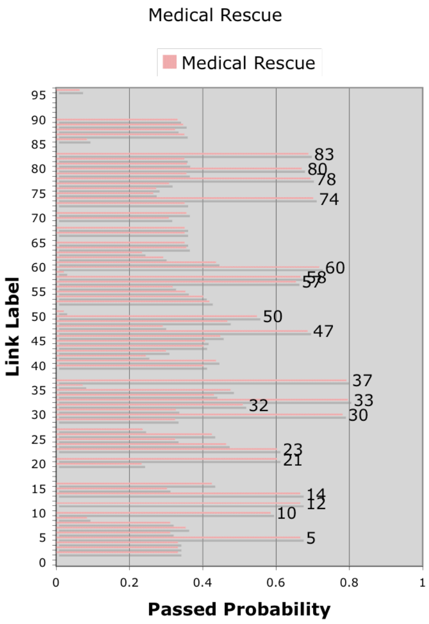


Figure 10. Dominant Medical Rescue Links

C. Logistics supply:

With respect to logistics supply, we used residential population gathered in open spaces over 10000m^2 and schools as the demand nodes. Because there is no harbor or airport in Lingya district, we took the entries of the roads as supply nodes, which are connecting to other districts and definitely passed wherever the logistics vehicles come. Input all the compositions of supply node and demand nodes in the enumeration algorithm. Setting 0.5 of probability as a limit of dominant links, we got the following result. Links of number 5, 10, 12, 14, 16, 30, 32, 33, 37, 47, 57, 58, 60, 74, 78, 80, and 83 are dominant links with respect to logistics supply.

Table 5. Passed Probabilities of Links with Respect to Logistics Supply

e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$	e_i	$P(e_i)$
0	0.000	20	0.250	40	0.412	60	<u>0.703</u>	80	<u>0.734</u>
1	0.000	21	0.465	41	0.452	61	0.411	81	0.383
2	0.351	22	0.000	42	0.361	62	0.364	82	0.383
3	0.351	23	0.494	43	0.374	63	0.346	83	<u>0.738</u>
4	0.351	24	0.457	44	0.413	64	0.354	84	0.000
5	<u>0.703</u>	25	0.398	45	0.415	65	0.367	85	0.000
6	0.363	26	0.454	46	0.447	66	0.000	86	0.000
7	0.363	27	0.377	47	<u>0.645</u>	67	0.367	87	0.383
8	0.363	28	0.000	48	0.389	68	0.367	88	0.384
9	0.046	29	0.398	49	0.435	69	0.000	89	0.384
10	<u>0.703</u>	30	<u>0.636</u>	50	0.488	70	0.401	90	0.384
11	0.000	31	0.410	51	0.176	71	0.354	91	0.000
12	<u>0.703</u>	32	<u>0.525</u>	52	0.000	72	0.000	92	0.000
13	0.000	33	<u>0.732</u>	53	0.454	73	0.367	93	0.000
14	<u>0.703</u>	34	0.406	54	0.405	74	<u>0.734</u>	94	0.000
15	0.351	35	0.455	55	0.403	75	0.310	95	0.000
16	<u>0.512</u>	36	0.239	56	0.378	76	0.322	96	0.046
17	0.000	37	<u>0.652</u>	57	<u>0.581</u>	77	0.346		
18	0.144	38	0.000	58	<u>0.598</u>	78	<u>0.707</u>		
19	0.288	39	0.144	59	0.046	79	0.354		

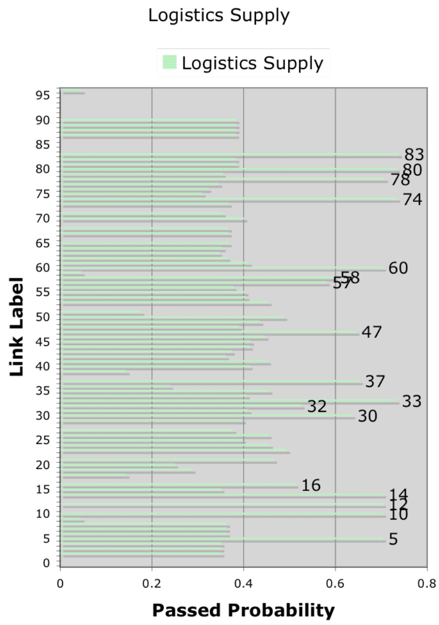


Figure 11. Dominant Logistics Supply Links

(4) Result of dominant links in common

We listed all the dominant links below and showed the intersection set among the three different activities. With the unique labels, we compared the labels in ArcView and checked out the names of each link.

Table 6. Road Labels and Names of Dominant Links

Respect	Labels of dominant links	Road names of dominant links
Fire rescue	5, 10, 12, 14, 21, 23, 30, 32, 33, 37, 47, 50, 60, 74, 79, 80, 83	Yungping Rd, Yungtai Rd, Lingya 2^{nd} Rd, Szuwei 4^{th} Rd, Lingya 1^{st} Rd, Chengkung 1^{st} Rd, Santo 3^{rd} Rd, Wufu 1^{st} Rd, Chienkuo 1^{st} Rd, Kaihsuan 1^{st} Rd, Fute 3^{rd} Rd, Fute 2^{nd} Rd, Santo 1^{st} Rd, Chungcheng 1^{st} Rd, Mingte St
Medical rescue	5, 10, 12, 14, 21, 23, 30, 32, 33, 37, 47, 50, 57, 58, 60, 74, 78, 80, 83	Yungping Rd, Yungtai Rd, Lingya 2^{nd} Rd, Szuwei 4^{th} Rd, Lingya 1^{st} Rd, Santo 3^{rd} Rd, Wufu 1^{st} Rd, Santo 2^{nd} Rd, Chienkuo 1^{st} Rd, Kaihsuan 1^{st} Rd, Fute 3^{rd} Rd, Fute 2^{nd} Rd, Chungcheng 1^{st} Rd, Mingte St
Logistics supply	5, 10, 12, 14, 16, 30, 32, 33, 37, 47, 57, 58, 60, 74, 78, 80, 83	Yungping Rd, Yungtai Rd, Lingya 2^{nd} Rd, Szuwei 4^{th} Rd, Lingya 1^{st} Rd, Chengkung 1^{st} Rd, Santo 3^{rd} Rd, Wufu 1^{st} Rd, Santo 2^{nd} Rd, Chienkuo 1^{st} Rd, Kaihsuan 1^{st} Rd, Fute 3^{rd} Rd, Fute 2^{nd} Rd, Chungcheng 1^{st} Rd, Mingte St
Common	5, 10, 12, 14, 30, 32, 33, 37, 47, 60, 74, 80, 83	Yungping Rd, Yungtai Rd, Lingya 2^{nd} Rd, Szuwei 4^{th} Rd, Lingya 1^{st} Rd, Santo 3^{rd} Rd, Wufu 1^{st} Rd, Chienkuo 1^{st} Rd, Kaihsuan 1^{st} Rd, Fute 3^{rd} Rd, Fute 2^{nd} Rd, Chungcheng 1^{st} Rd, Mingte St

In the case, we found that the demand nodes scattered evenly in this district. And the shape direction of the district is a wide stripe with long road segments in east-west direction, and short road segments in north-south direction. We observed that most dominant links were concentrated on segments of 5, 12, 21, 23, and 30 (Lingya Road), and 32, 33, 37, 50, 57, 58, and 79 (Santo road). Both of which paralleled to the east-west direction of the shape. In order to cover and reach majority of the demand nodes, links of east-west direction will be passed more frequently. We suspected that it would be one of the reasons why these links were dominant links.

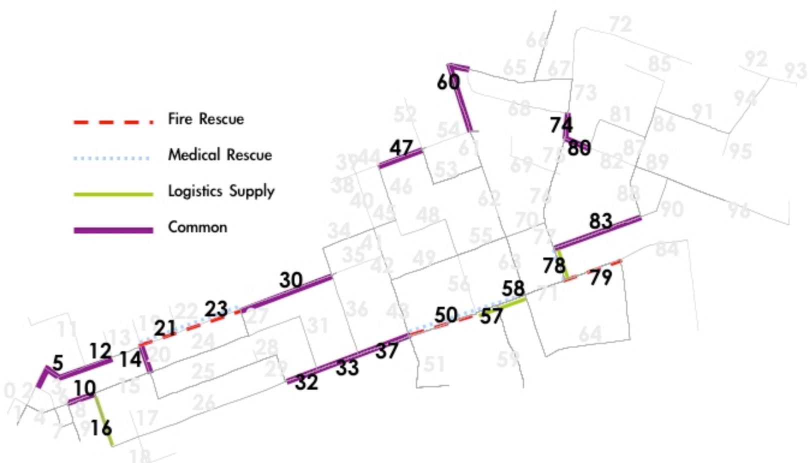


Figure 12. Map of Dominant Links

6. CONCLUSIONS

Road network plays an important role in disaster prevention system. It communicates many activities after disaster. As we take in consideration, there are at least three important activities after earthquake: fire rescue, medical rescue, and logistics supply. We planed a road network with emergency paths for the three activities satisfying both rapidity and comprehension. We also proposed important concepts, i.e. network scales and dominant links. The scales of road network may help us to figure out which pattern of road network is good for disaster prevention. Dominant links are segments of emergency paths and used the most frequently. The aim of finding out dominant links is to maintain them workable after earthquake, because we know these links can control most possible paths to make demand nodes and supply nodes accessible to each other.

The information of dominant links is valuable for network planning and management. Since destruction of these links will significantly reduce the possible replaceable paths in this area, government authorities should pay special attention to maintain these links. The investment strategies may be the engineering measures to improve road structures. Other traffic management such as controlling the amount of on-road parking spaces can ensure enough road width of dominant links. In addition, improving land use and building regulations can prevent indirect damages affecting these roads.

In this paper, we also constructed the relationships of road network by adjacency matrix and incidence matrix. And we showed how to use the relationships to enumerate replaceable paths in a road network through several steps. Finally, we used the enumeration algorithm in a practical case, Lingya district of Kaohsiung in Taiwan. The result revealed that the number of dominant links of fire rescue, medical rescue, and logistics supply, are 17, 19, and 17 respectively. The number of dominant links in common is 15. It will be valuable information to keep these roads communicable so that most part of nodes will not falling into isolation. Hence, it will better the environment of road network to let people safe in this area and far away from danger.

REFERENCES

Civil Affairs Bureau (2001) Civil Affairs Bureau, Kaohsiung City Government, Taiwan, ROC. Http://cabu.kcg.gov.tw/.

Cormen T.H., Leiserson C.E., Rivest R.L. and Stein, C. (2001) Introduction to Algorithms. McGraw Hill, USA.

Delaune, M. (1990) Xtool Extension. Http://gis.esri.com/arcscripts/scripts.cfm.

ESRI (1992) **ArcView GIS.** Environmental Systems Research Institute, Inc., New York.

Gunay, B. (1999) Modeling lane discipline on multilane uninterrupted traffic flow, **TEC, Vol. 40, No. 9,** 440-447.

Ho, M.J. and Lee, W.I. (1998) Study on the disasters prevention-function of physical environment in a city through comparing with urban disaster prevention system. Architecture and Building Research Institute, Ministry of the Interior, ROC. (in Chinese)

Hou, P.H. (2002) Evaluating on transportation functions of urban road system and proposing disaster-prevention road network system after earthquake disaster. Thesis. Institute of Traffic and Transportation, National Chiao Tung University, Taiwan, R.O.C.

Lee, W.I. and Qian, X.T. (1999) Study on the functions of urban disaster-prevention of physical-environments in a city through comparing with the urban disaster prevention system part II. Report No. MOIS881014, Architecture and Building Research Institute, Ministry of the Interior, ROC. (in Chinese)

Sun Microsystems (2003) **Java.** Sun Microsystems, Inc.

West, D.B. (2001) Matrices and isomorphism. **Introduction to graph theory**. Prentice-Hall, New York.