ANTI-DISASTER PLANNING BASED ON THE INFORMATION FLOW CHARACTERISTIC ON SOCIOMETRIC NETWORK

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ABSTRACT

The progress of science and technology has been tremendous in last 2 decades, especially in the Information Technology Field. We, civil engineers, are adopting more and more computerized analysis techniques for a growing variety of applications; such as, increasing construction efficiencies, environmental integrity, designing a safer city life-style, disaster prevention systems and so on. However, the impacts of natural disasters have not been suppressed or even controlled by the advanced scientific techniques, also known as hard technologies, now being employed. The magnitude of loss and suffering may continuously increase due to the concentration of population centers on major rivers or coastline harbour locations. The risk potential for these cities is increasing day by day.

In our paper, we first describe the Disaster Prevention Management elements as an action diagram with detailed inter-relations, which further shows the important influence of the information flow network structure. After simulating a socio-metric network, we finally propose the robust disaster prevention system.

KEY WORDS

natural disaster, information flow, network structure, average vertices distance, clustering

INTRODUCTION

In the early morning of 17 January 1995, a huge earthquake (Magnitude 7.2 on the Richter scale) struck Kobe City, located within the 2nd active sphere (Oosaka) of west-Japan, and resulted in 6,443 deaths. It was reported that about 5,000 died due to the sudden collapse of buildings, houses and the affects of fires. The regional government office building, which should be the anti-disaster command center, was the first to collapse. As a consequence, not only were internal power, telephone & computer devices affected, the entire communication system was disrupted. It was 4 hours after the earthquake before the Governor of Hyogo Prefecture could request civil-defence emergency troops, fire service special units, and the other official support organizations to rescue lives. In the so-called '4 hours blank', it is not

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hard for us to imagine that over 1,000 lives might have been saved, if the communication system of Kobe City was robust enough to cope with such an emergency.

We have learnt from the Kobe sorrowful experience, and developed information technology (IT) applications significantly at the end of 20^{th} century, including the research development and adoption of a Geographical Information System (GIS) for future natural disasters.

On the 28^{th} October 2004, almost 10 years after Kobe, a similar scale earthquake struck the small cities of Niigata Prefecture, which fortunately was not so densely populated but still resulted in 40 deaths. The communication isolation or poor communication problems have not been fully resolved even with the utilization of advanced IT methods [Suzuki, 2005a]. Computing and/or advanced science technologies are developed day-by-day and the benefits are deeply infiltrated into our normal life, however their application to enhance our ability to deal with emergency situations has not been fully evaluated.

In our research, we firstly surveyed the actual IT systems (such as GIS anti-disaster system) adopted by several regional government offices. Secondly, we inquired in communities about the communication linkage as a network system based on the hypothesis that the effectiveness of disaster prevention should be dependent on the information transmission structure. The characteristics of the derived network are described and analyzed using formulae for graph theory and network structures to conclude, and propose a robust communication structure.

ANTI-DISASTER PLANNING & IT SYSTEM

The Ministry of Health, Welfare and Labor developed the 'wide-range disaster emergency hospital information exchange system' after Kobe. The main feature of this system is that all emergency hospitals, regardless of being government or private, should be able to exchange assistance capabilities on a real-time basis. This system was however not utilized in the Niigata's case, and perhaps worse, it took almost one month to find this out.

We visited the persons in charge of the disaster prevention departments of five regional government offices to determine and understand the efficiencies of the GIS or similar anti-disaster IT systems currently in place. From information collected, we classified key words and displayed them on a relationship map, from which it is clear that the main reason for IT systems not being used is the inconsistencies between the anti-disaster working flows and the IT system processes [Suzuki, 2005b].

In *Figure 1* we depicted the process flow chart for regional government offices anti-disaster planning based on the Disaster Prevention Basic Law regulated by the central government. From further investigation of the disaster prevention planning for all hierarchical government structures, we found that all planning of each layer was more less same, and that the major emergency teams have their own vertical command systems which are non-integrated as depicted in *Figure 2*.

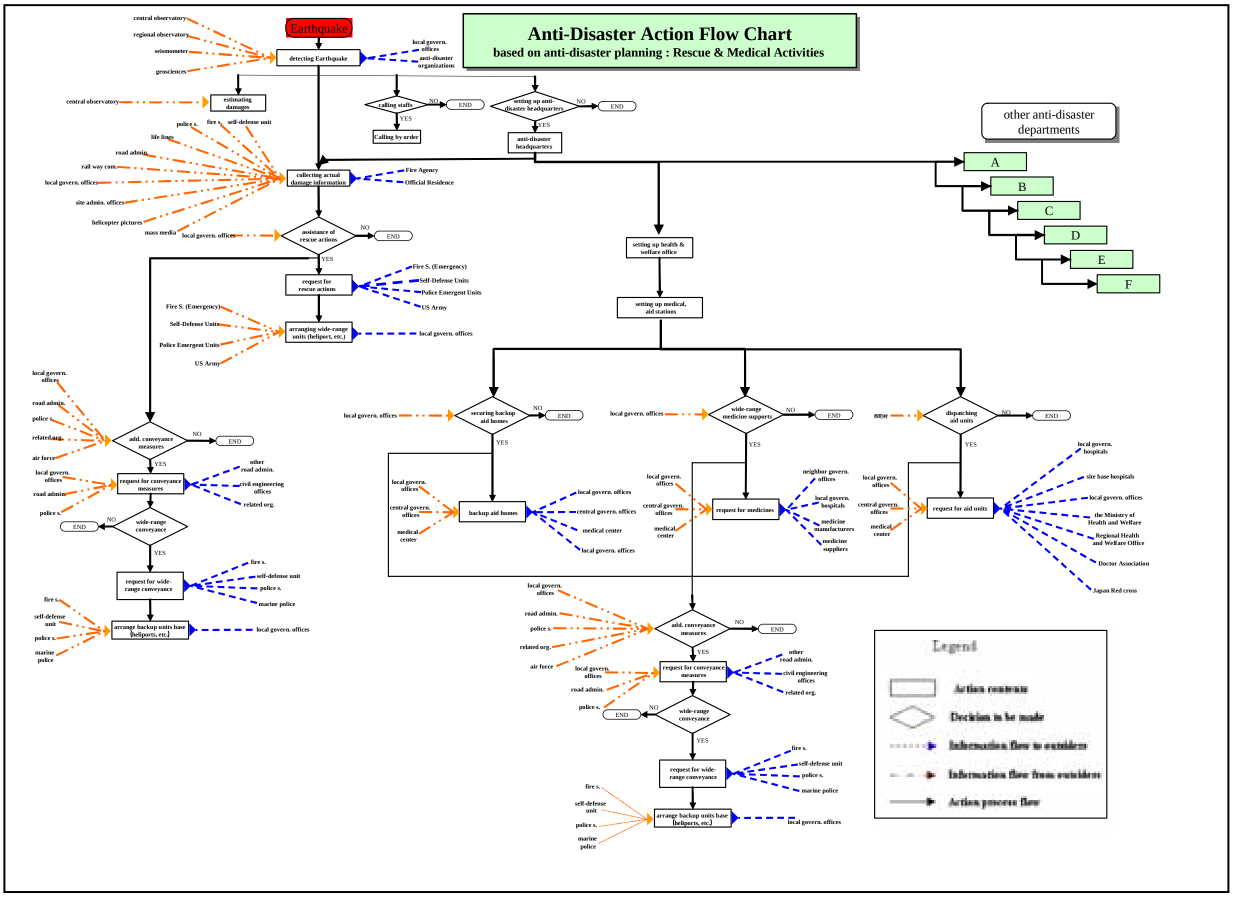

Figure 1: Anti-Disaster Action & Information Flow Chart for Rescue & Medical Activities

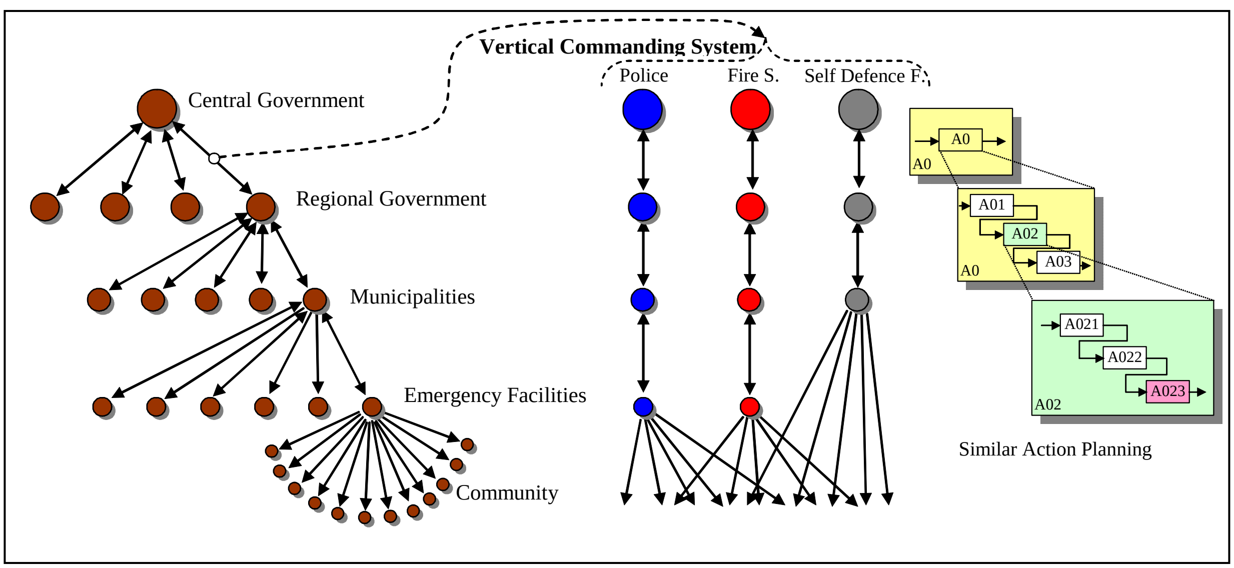

Figure 2: Hierarchical Government Structure & Vertical Command System

INFORMATION NETWORK IN COMMUNITY

For effective disaster prevention, attention must be given to ensure the full scope of capability cooperation between government organizations and communities. From the research in the previous chapter we attained a good understanding of the processes & information flows within government organizations. Our investigations were subsequently broadened to evaluate information exchanges and transmissions by the public and communities during a crisis.

We prepared an inquiry form for the public to mark the persons or organizations to be contacted in case of facing an unexpected disaster. We studied two different communities; (a) the first was the newly developed high-raised condominium, and (b) the second was the shopping district developed a long time ago. Community (a) has a three-dimensional space, whilst (b) is two dimensional from a physical point of view. Graphical presentations of both communities are depicted in *Figure 3*, where the circles show representations for each community member, and the linkage to external organizations shown outside.

The first impression is that community (a) is denser than (b) however, the density of network systems (a) and (b) is 0.0096 and 0.0305 respectively. The information concentrated on the external nodes for fire station, police station and neighborhood associate are highlighted by a ring or dotted ring in *Figure 3*. These nodes are likely to cause the information bottle-neck phenomena as these represent the key connection points between the public and government organizations. It is clear therefore that some other inter-connection organizations, such as NPOs (non profit organizations) and volunteer centers, if organized systematically in anti-disaster planning would significantly improve the effectiveness of disaster determent, as proved by Suzuki (2005c).

The connection of community (a) is evenly distributed whilst in (b) some nodes have many links. We could interpret that it could take some time to train some community members to be anti-disaster readers.

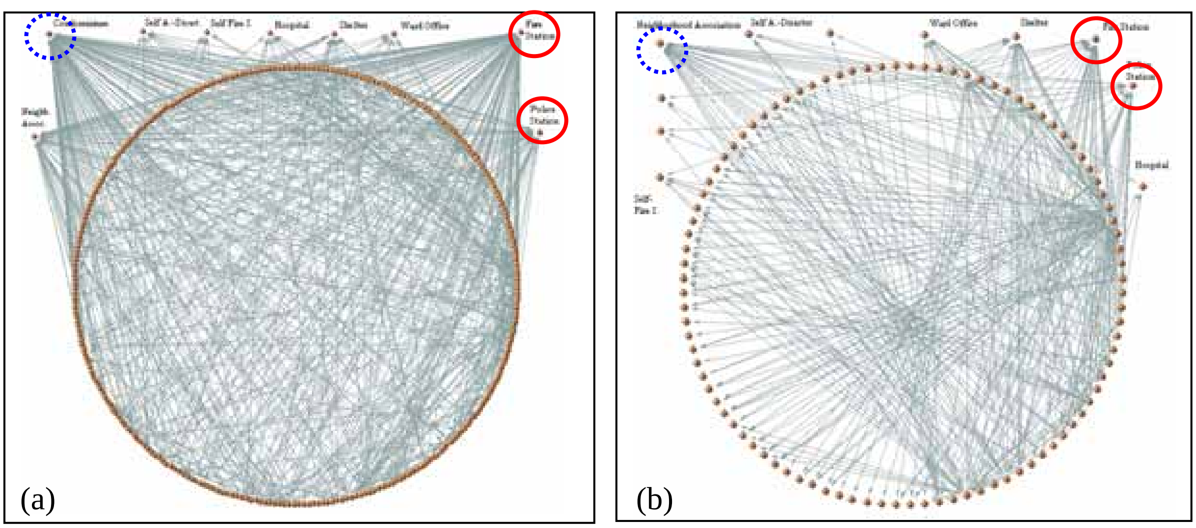

Figure 3: Graph expressions of communication network in immediate crisis

NETWORK STRUCTURE AND GRAPH THOERY

THE ANALYSIS OF NETWORK STRUCTURE BY GRAPH THEORY

We visualized the anti-disaster planning regulated by regional government offices and the information network for two kinds of community in the previous chapters. In this chapter we give an outline on how to understand or read the characteristics of a network system.

Figure 4 shows network structures which have the same number of nodes (108) in the system, but a different number of links (107 & 193). On the left side, *Graph (c)* appears as a 'Tree shaped' which is expanding from the center *node 'A'* and outward into unlimited space. This structure has hierarchies and physical characteristics which can be applied to any scale of system. The right side *Graph (d)* shows complicated connections between nodes or vertices.

If *node 'A'* is deleted from the both systems, the system depicted in *Graph (c)* would totally break down with no information being transmitted at all, whilst on the other hand the system represented by *Graph (d)* would not be affected. By observation, it is also clear from *Graph (d)* that the competence of information conveyance will not vary very much even if more and more nodes are deleted. Similar observation of the graph topologies tells us that the information transmission flow and efficiency would be more direct and therefore better in *Graph (c)* as compared to *Graph (d)*. This is easily demonstrated by simple calculation of the steps required to deliver the information from one end of the network to the other (Graph (c) = 8, Graph (d) = 11).

It is clear that the relationship between efficiency and robustness of information conveyance is trade-off, and society is composed of the efficient structure.

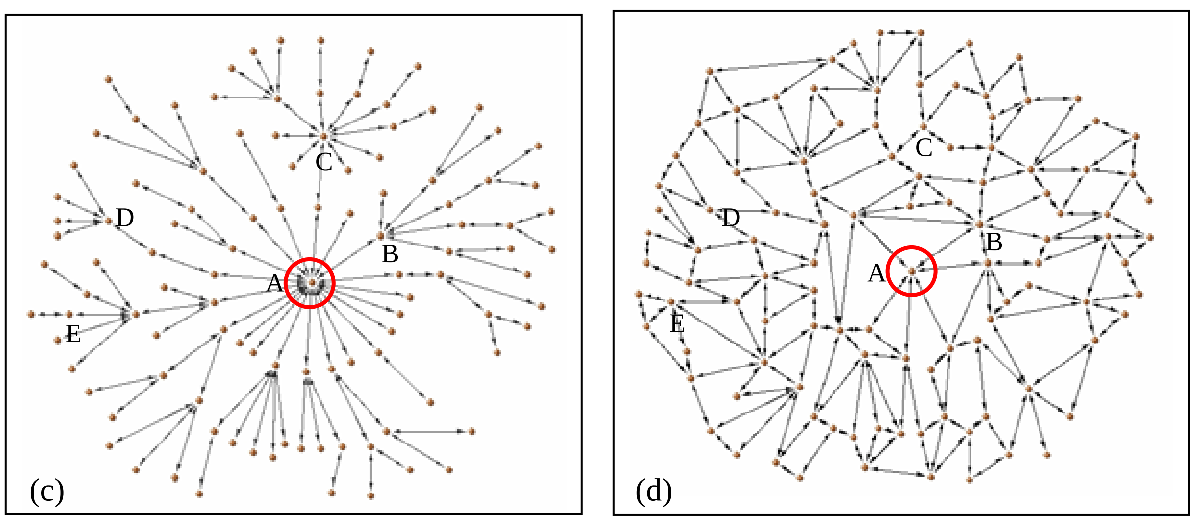

Figure 4: Network Structures (Tree shaped network & Complicated conection network)

The overall network centralities can be calculated by adopting the following graph theory formulae:

- Degree centrality

  This index shows the extent of affection and information concentration, where x_{ij} is the number of links from node i to node j.

$$Degree(n_i) = \frac{1}{n-1} \sum_{\forall j \neq i} x_{ij} \qquad (1)$$

- Closeness centrality

  Closeness shows the approach-ness of node i in the network system. It is not the physical distance, but the reciprocal of the shortest step, where $d(n_i, n_j)$ is the shortest distance (step) from node i to node j.

$$Closeness(n_i) = \frac{n-1}{\sum_{j=1}^{n} d(n_i, n_j)} \qquad (2)$$

- Between-ness centrality

  Between-ness shows the brokerage of transmitting information in the network, where $g_{jk}(n_i)$ is the shortest steps from node j to k passing through node i, and g_{jk} is all possible shortest steps from node j to k.

$$Between-ness(n_i) = \sum_{j<k.i \neq j, i \neq k} \frac{g_{jk}(n_i)}{g_{jk}} \qquad (3)$$

Using the above formulae we calculated the *Figure 4 Graph (c) & (d)* network characteristics to be as follows:

Table 1: Characteristics of *Graph (c) & Graph (d)* by Graph Theory Formulae

node	Degree		Closeness		Between-ness	
	graph (c)	graph (d)	graph (c)	graph (d)	graph (c)	graph (d)
A	0.1869	0.0561	0.3905	0.2616	10,372	2,178
B	0.0561	0.0654	0.3057	0.2662	2,934	3,102
C	0.0935	0.0374	0.2572	0.1953	3,304	1,361
D	0.0467	0.0374	0.1904	0.1823	836	347
E	0.0187	0.0467	0.1924	0.1698	212	444

It is easy for us to understand from the calculation results that *node 'A'* of *Graph (c)* has a very heavy burden within the network system, whilst all nodes of *Graph (d)* share the overall responsibilities. Between-ness indices of *Graph (d) nodes 'D' & 'E'* are lower because of the influence of modeling (system edge problem).

THE CHARACTER OF SCALE-FREE NETWORK

It has been discovered by A.L Barabashi (1999) that the internet has not been connected at random. Whilst a few number of sites have a huge mumber of links, such as google & yahoo, most sites have only 10 links or less. Using the "power law", we can draw a strait line on the x & y axes (both logarithm) to represent the artificial products or natural objects around us in a network structure. Most of them have this same structure, which is also known as a scale-free network because it is not scale dependent. Hierarchical and fractal structures normally have the characteristics of a scale-free network.

There are two simple rules to produce a scale-free network; 1) the network is evolving, 2) a new node connects preferentially. In *Figure 5* the logarithm y-axis shows the number of connected links and the logarithm x-axis shows a ranking of surveyed communities for *Graphs (a) & (b) of Figure 3*.

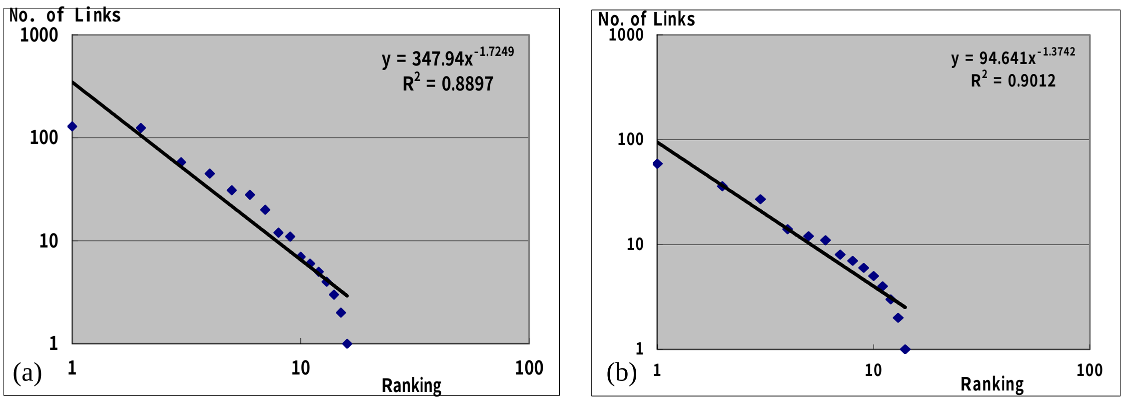

Figure 5: Network Charactristic of Community

We found that the characteristics of each different type of community are in fact very similar and consistent with the "power law", though they do not fit completely to the characteristics of a scale-free network, because there are the top and tail cut-offs on both graphs.

Amaral (2000) determined that the top cut-off was a broad-scale network in which there should not be a node with a huge number of links similar to the limitation of humans in real life, and that the tail cut-off was a single-scale network where the hub could not maintain many links due to financial or physical limitations.

The most notable feature of a scale-free network is its robustness against random attack and the fragileness against targeted strikes (Albert 2000, Jeong 2000).

THE CHARACTER OF SMALL WORLD NETWORK

One year before the scale-free network was discovered, Watts (1998) put forward an interesting network topology called "small world" published on 'Nature'. The small world network is somewhere between regular & random structures, but interestingly a feature of this network topology is that the clustering coefficient (C) is much bigger than the random network's one and the average distance between nodes ($\langle L \rangle$) is similar. This short $\langle L \rangle$ means that it should be easier to distribute/transmit information even in a large network such as the social system.

Calculation formulae for clustering coefficient and average distance betweeb nodes are described as follows:

- Clustering coefficient

  Clustering coefficient is that the possibility of direct friends who two are ones' friend in our society. C_i is the possibility of actual existence E_i against the possible combination ${}_{k_i}C_2 = k_i(k_i - 1)/2$. C is the average of C_i.

$$C = \frac{1}{n}\sum_{i=1}^{n} C_i \qquad C_i = \frac{2E_i}{k_i(k_i - 1)} \tag{4}$$

- Average distance between nodes

  Average distance between nodes $\langle L \rangle$ is the average of shortest path length (steps) against all pairs of node in the system.

$$\langle L \rangle = \frac{1}{n(n-1)}\sum_{i=1}^{n}\sum_{j=1}^{n} d(n_i, n_j)(i \neq j) \tag{5}$$

The small world phenomena are appeared on the particular network topology, which has the relationship between C & $\langle L \rangle$ as shown below;

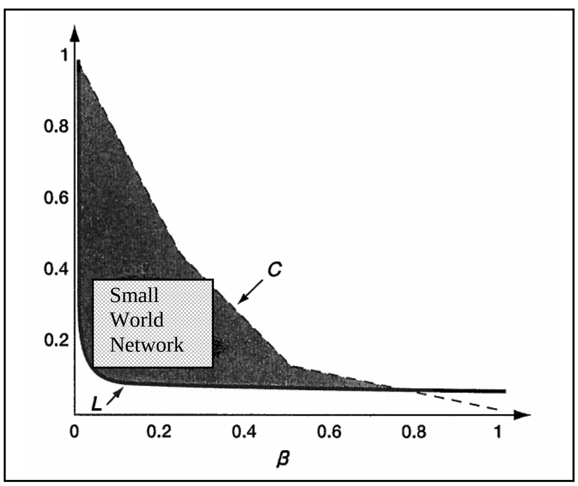

Figure 6: Specific Area of Small World Phenomena as a Network

β is the probability of link re-connection. β =0 means no reconnection (regular network). β =1 means randomly reconnected. Small world phenomena gives the large C and the small $\langle L \rangle$.[Watts,2003]

SIMULATION FOR ROBUST DISASTER PREVENTION NETWORK TOPOLOGY

We have noted that if any administrative offices have a hierarchical structure which composes a scale-free network, then it should be robust against radom attacks such as natural disasters. However, in the event of a large scale earthquake, many important hubs might be damaged, as happened in the Kobe case. We might conclude that the social network, including communities & administrations, should have a disaster scale dependance structure.

From the surveyed emergency information network system of all layers of organizations and communities, the direct connection points between citizen and administrative offices should be the municipalities. If we depict the emegency information transmission network which includs a malfunctioned node of a municipality office in a large city as a simulation model (*Figure 7; Figure 4 Graph (c)* 'Tree shaped' applied), we can see how the network topology will be changed from "scale-free" to 'small world' where the average distance between nodes $\langle L \rangle$ is smaller. The simulation results are shown in *Table 2*.

The re-connection method of links in *Figure 8* is that (a) isolated nodes on the upper & lower hierarchical layers are binded, (b) a few long-short cuts beyond malfunction node C are added. The average distance $\langle L \rangle$ of *Figure 8* is smaller than the original's one.

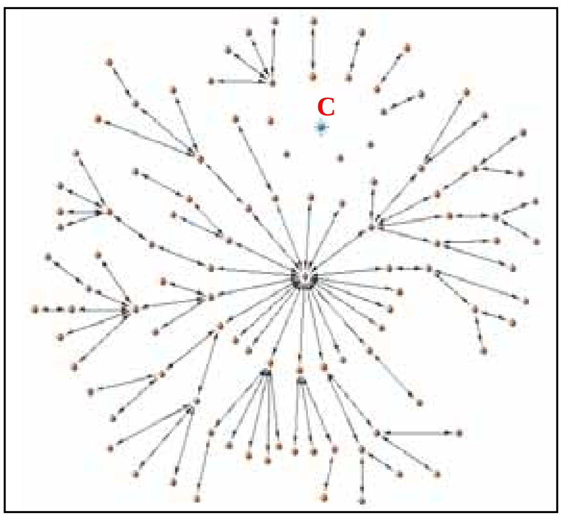

Figure 7: The Node C Malfunctioned as a Simulation Network

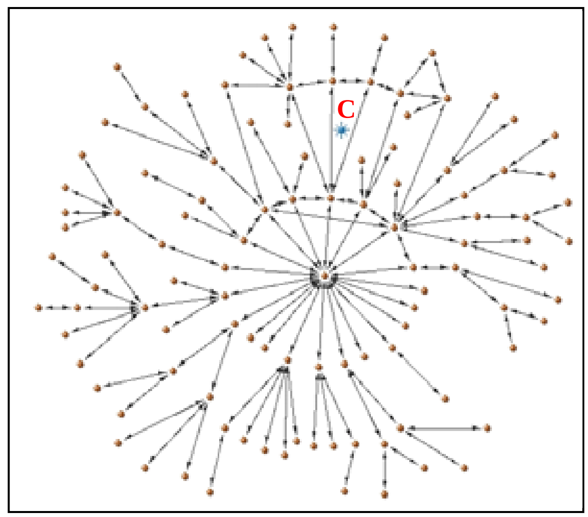

Figure 8: Minimized L with a few links (Small World Long-Short Cuts)

Table 2: Simulation Result

	Clustering Coefficient C	Average Distance <L>	Max. Distance
Figure 3 (a) 3-D Community	0.006358	2.87081	6
Figure 3 (b) 2-D Community	0.032303	2.57170	5
Figure 4 (c) Tree shaped (original)	0.000000	4.80651	8
Figure 7 +hierarchical binding	0.001578	5.00194	10
Figure 8 +5 short cuts	0.006232	4.47152	8

CONCLUSIONS

When huge disasters occur suddenly, everybody panics and the social mechanism falls into chaos. The ensuing breakdown in communication and availability of information makes the situation worse, delaying recovery and ultimately resulting in avoidable loss of life.

In this paper we have highlighted the information flow structure for communities and administration organizations in an emergency. From our research, we found that there should be some information bottle neck organizations between the public and administrative offices, and that actual societies construct the most efficient relationship in the form of a "scale-free network", though this is fragile against un-predictable huge disasters. We have analyzed a robust information network topology in the immediate emergency by using the "small world phenomenon" which has 'long-short cuts' beyond the disaster scale for anti-disaster planning.

As long as the system can be described by a network (no matter how complicated) the individual key players and the functioning of the overall system should be clear, though as the matrix data format for simulation is tremendously large, critical decision making will largely be supported by advanced computerized analysis techniques. We believe our research can provide the effective & robust 'balanced' social system against un-predictable disasters.

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