A Preliminary Study on the Vulnerability of the Metro Taipei

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ABSTRACT: The vulnerability refers to weakness and risk of a system and its recovering ability after suffering a disaster. It has been widely used to evaluate an ecological or an environmental system. In this paper, we introduce the three index, (1)exposure, (2)sensibility, and (3)adaptability, proposed by the IPCC of the United Nations, to evaluate the vulnerability of a transportation network – the Metro Taipei. The exposure is defined as the risk of accidents and the pressure on the network, such as the inundation scenarios and the passenger flow of a station. Once an unexpected event affects the system will cause tremendous inconvenience to the passenger. The sensibility is defined as the centrality of the network. Three centrality index of each node(station) are calculated: (1)degree, (2)closeness, and (3)betweenness, to find the sensitive nodes of the network. The degree centrality is the in-connections and out-connections of a node. The closeness centrality means how close a node is to other nodes of the network. The betweenness centrality reveals how many times a node would be passed through between any two other nodes. The Girvan and Newman grouping method is applied to decompose the network into sub-networks. A sub-network can be taken as a local network. The adaptability is defined as the recovering ability or the alternatives while a node is suffering an accident. The nearby bus stops and public bike stations are considered as the alternatives while a metro station is becoming disabled. The more bus stops or public bike stations means higher adaptability of a metro station. We propose an integrated vulnerability index to considering the exposure, the sensibility, and the adaptability of each station. The integrated vulnerability index is then visualized on the map for better illustration of the negative impact and the positive recoverability of the Metro Taipei.

1.INTRODUCTION

1.1 Background

The Intergovernmental Panel on Climate Change(IPCC) Fourth Assessment Report in 2007 proposed three index of vulnerability: (1) exposure, (2) sensitivity, and (3) adaptability. Major Researchers followed this definition to evaluate the impact when an ecological or an environmental system suffer from climate change. According to the Taipei Rapid Transit Corporation (TRTC) who operates the Taipei Metro System, the Metro Taipei carried 1,965,786 passengers per day. Once an unexpected event affects the system will cause tremendous inconvenience to the passenger. In this study, we use three vulnerability index to analyze the network of Metro Taipei. The road network is composed by linkages and nodes(Taaffe *et al.*, 1996), (Taaffe *et al.*, 1996)and there are two different linkage:(1) physical, such as railway (2) abstract, such as airway(Sussman, 2002), and the node were both physical in the real world. Porta *et al.* (2006) use centrality index to analyze the Melbourne public transport system, and deep discuss the linkage from the angle of efficiency. Our study try to use the same centrality index, and combine with the view of vulnerability to analyze the Metro Taipei. Rodríguez-Núñez *et al.* (2014)apply the vulnerability model to find out those significant linkages. He measures the Madrid public transport system vulnerability, and he use the real time data to simulate the research. This paper tries to answer two main questions:

(1) Identify the critical station in the Metro Taipei.
(2) Built up a vulnerability Model to estimate the metro network system.

1.2 Study Area

The Metro Taipei currently includes five main lines: Wenhu Line, Tamsui-Xinyi Line, Songshan-Xindian Line, Zhonghe-Xinlu Line and Bannan Line, serving over 2 millions ridership per day. The operating city include Taipei City and New Taipei City. The network form by 107 stations and operating on 131.1 kilometers. (Figure 1)

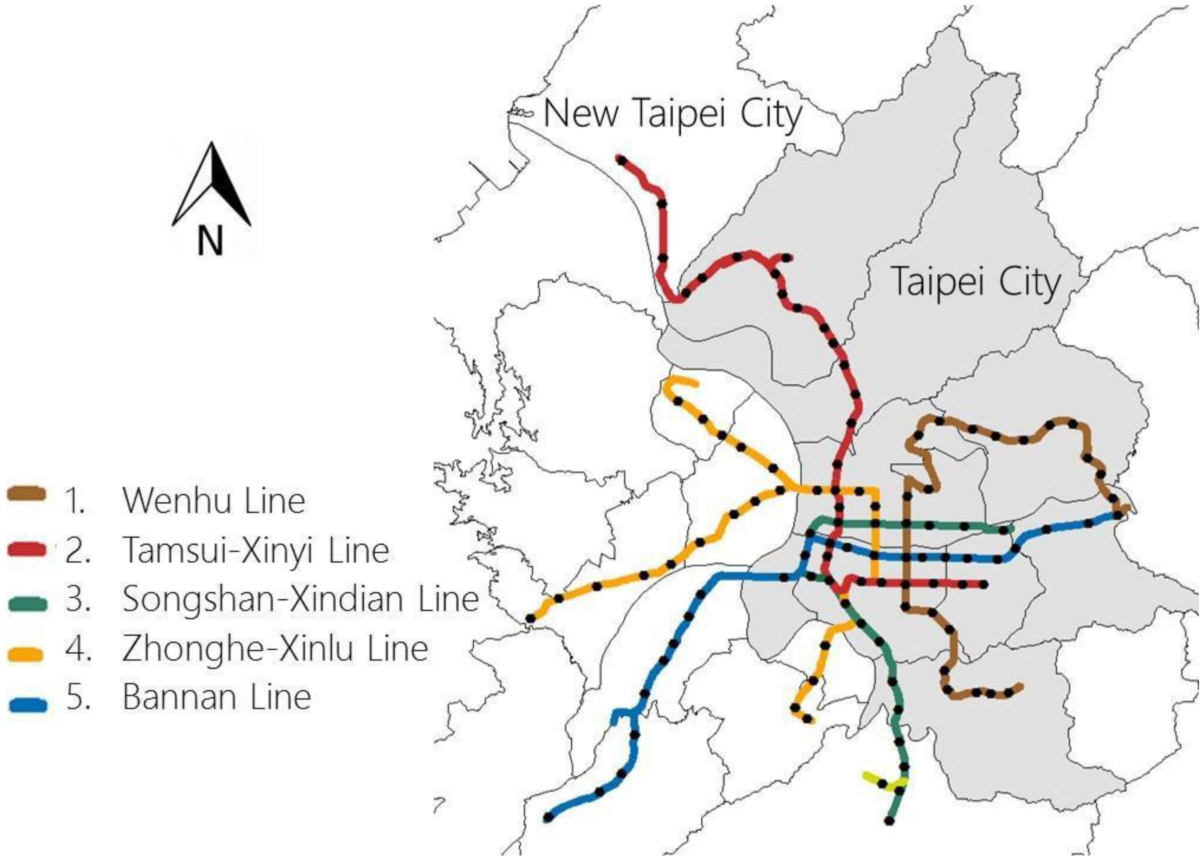

Figure 1 Metro Taipei network

2.METHOD

In this paper, we use the ridership Statistics and inundation scenarios to measure the exposure of a station. Then, we use three centrality index to calculate the sensitivity of a station. Eventually, adaptability is calculated by the surrounding alternatives (such as: bus route, bicycle-sharing system). By aggregating three above index, we get a vulnerability index to measure a station. (Figure 2)

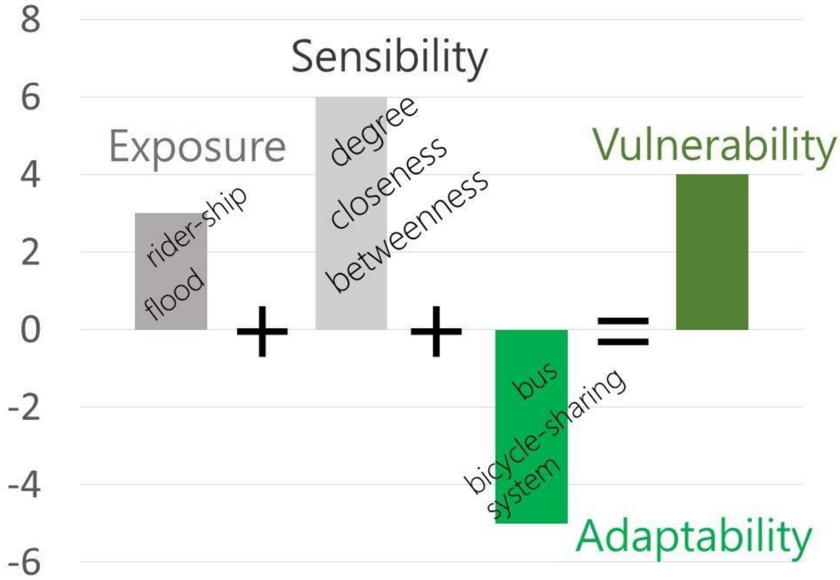

Figure 2 The concept of Vulnerability Model

2.1 Exposure Factor

We overlap inundation scenarios map with ridership of each station, to capture the exterior pressure. We assume that more people a station carry, the risk of unexpected accident will become higher. These two factors will be normalized to value 0~1.

2.1.1 Inundation Scenarios Factor

In order to identify the which station may be affected by flooding, we use within 72 hours accumulated 1200 mm of precipitation inundation scenarios Map (Water Resources Agency, Ministry of economic affairs, Taiwan), simulating the inundation regions of Taipei City. (Figure 3)

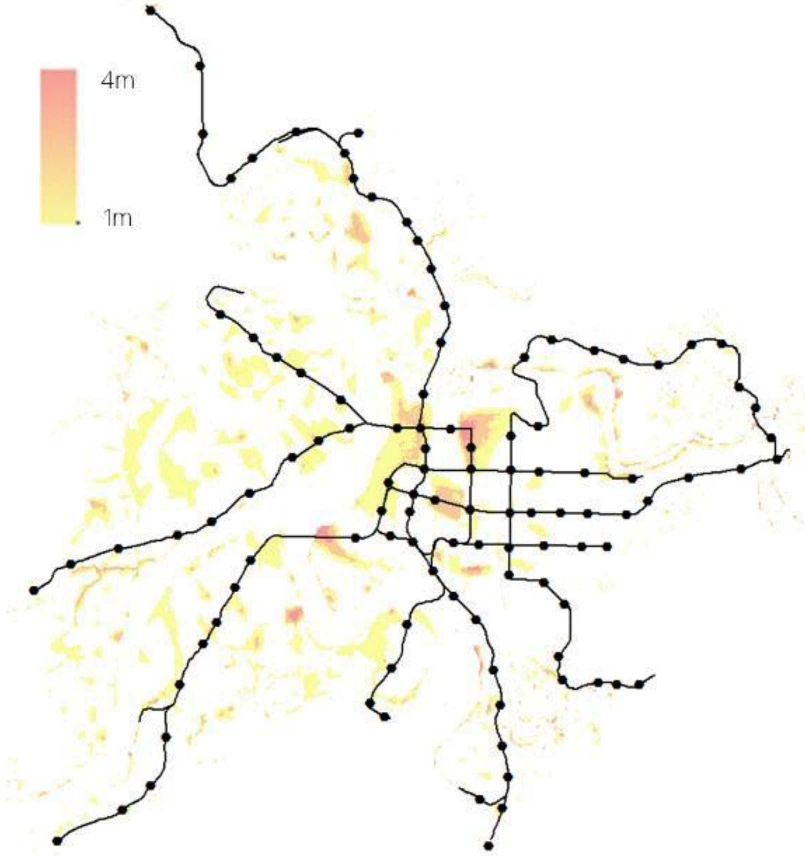

Figure 3 Inundation scenarios Map layout with Metro Taipei

2.1.2 Ridership Statistics Factor

We calculate the 2015 ridership of each station, to measure the operating pressure from passengers. (Equations 1)

$$(P_i) = \frac{P_{Pi} - P_{min}}{P_{Max} - P_{min}} \quad \text{(Equations 1)}$$

where P_i is the station in the network,
P_{Pi} is the ridership for the station P_i,
P_{Max} is the minima ridership for the station,
P_{min} is the maxima ridership for the station.

2.2 Sensitivity

In the field of network analysis, centrality is a very significant index to identify which node is important in the network. In the field of transportation network, if a node's centrality index are higher than others, it will be identified. It's means that node in the transportation network is more vulnerable, once it is malfunction, it will cause tremendous impact on the system. The centrality index is consisted of three part: (1) degree(Equations 2), (2) closeness(Equations 3), and (3) betweenness.(Equations 4).(Freeman, 1978) Degree counts the linkage of a node, and it is distinguished two form: (1) in-degree(I connect to others), (2) out-degree(Others connect to me). Closeness can mark those very central node, whom can reach any node in the network by a short path. Betweenness will identify the "bridge" node, those node occupy the shortest path in any pair nodes in the network. By calculating these centrality index, we can mark those important hub nodes in the network.

2.2.1 Degree Centrality

$$C_D(P_i) = \frac{di}{N-1} \quad \text{(Equations 2)}$$

where di count the linkages of the station P_i,
N is the total station in the network.

2.2.2 Closeness Centrality

$$C_c(P_i) = \left[\sum_{j=1}^{N} d(P_i, P_j)\right]^{-1} \quad \text{(Equations 3)}$$

where $d(P_i, P_j)$ is the relationship distance of node P_i and node P_j in the network.

2.2.3 Betweenness Centrality

$$C_B(P_i) = \sum_{j<k} g_{jk}(P_i) \,/\, g_{jk} \quad \text{(Equations 4)}$$

where $g_{jk}(P_i)$ counts the times that node P_i occup the shortest path of node j and node k in the network,
g_{jk} counts the shortest paths of node j and node k in the network.

Closeness and Betweenness centrality are well used in Crucitti *et al.* (2006)'s paper, this study regard road intersection as a node, and road as a linkage. They can distinguish the urban street pattern very clear, and capture the difference between the city since ancient times and new urban planning city. Closeness and Betweenness centrality were used to measure the global flight network. Guimerà *et al.* (2005) applied two centrality index to analyzed the flight network structure and characteristics. The author also uses Girvan-Newman Technique method to group the airport, to see what airport play an important role in the flight network.

2.3 Adaptability

We calculate the bus routes and public bicycle sheds within 100 meters of the station's exits. By normalizing and aggregating above two factor, we can know the recovery ability when the station suffers from an accident event.

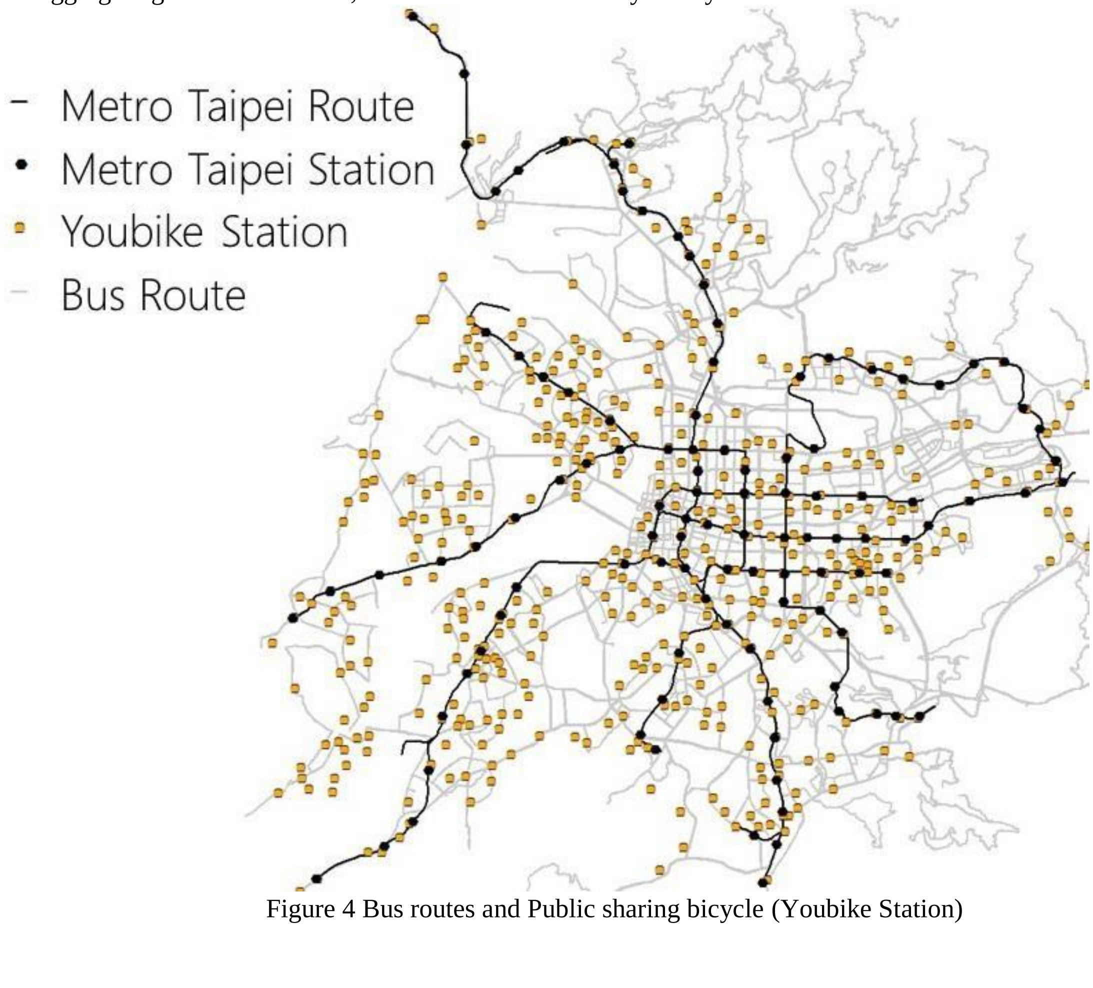

Figure 4 Bus routes and Public sharing bicycle (Youbike Station)

2.3.1 Bus Factor

$$A_S(P_i) = \frac{S_{Pi} - S_{min}}{S_{max} - S_{min}} \quad \text{(Equations 5)}$$

where S_{Pi} counts the station's bus routes,
S_{Max} is the maxima bus routes of the station in the network,
S_{min} is the minima bus routes of the station in the network.

2.3.2 Bicycle Factor

$$A_B(P_i) = \frac{B_{Pi} - B_{min}}{B_{max} - B_{min}} \quad \text{(Equations 6)}$$

where B_{Pi} counts the station's public bicycle sheds,
S_{Max} is the maxima public bicycle sheds of the station in the network,
S_{min} is the minima public bicycle sheds of the station in the network.

2.4. Vulnerability Model

2.4.1 Before Adjust

$$Vul_{pi} = \frac{F_{pi} + E_{pi}}{2} + \frac{D_{pi} + C_{pi} + B_{pi}}{3} \quad \text{(Equations 7)}$$

where F_{pi} is inundation scenarios factor,
E_{pi} is ridership statistics factor,
D_{pi} is degree centrality factor,
C_{pi} is closeness centrality factor,
B_{pi} is betweenness centrality factor.

2.4.2 After Adjust

$$Adj\_Vul_{pi} = Vul_{pi} + \frac{A_S + A_B}{2} \quad \text{(Equations 8)}$$

where A_S is the bus factor,
A_B is the bicycle factor.

3. RESULT

3.1 Sensitivity

Our approach uses centrality index to identify those significant stations(Figure 6A black line). The trend of sensitivity calculation result is well fit with closeness centrality(Figure 6A yellow line). The closeness centrality calculated the relationship distance between nodes, those nodes with high closeness centrality represent they stand in the very center of the network. The stations from the right to left corresponding high sensitivity to low sensitivity(Figure 6). We find that the trend goes up dramatically in Daqiaotou station (Figure 6B), and we consider the fifteen stations from the right as high sensitivity stations(Figure 6A blue circle enlarge in Figure 6B). These fifteen stations are marked in the Figure 7 and most of them are major transfer stations. It is worth mentioning that we find two important stations: 12.Shuanglian station and 13.Sandao Temple, these two stations' location occupy lots of the shortest route in any pair node in the network, their betweenness centrality are higher than most transfer stations.

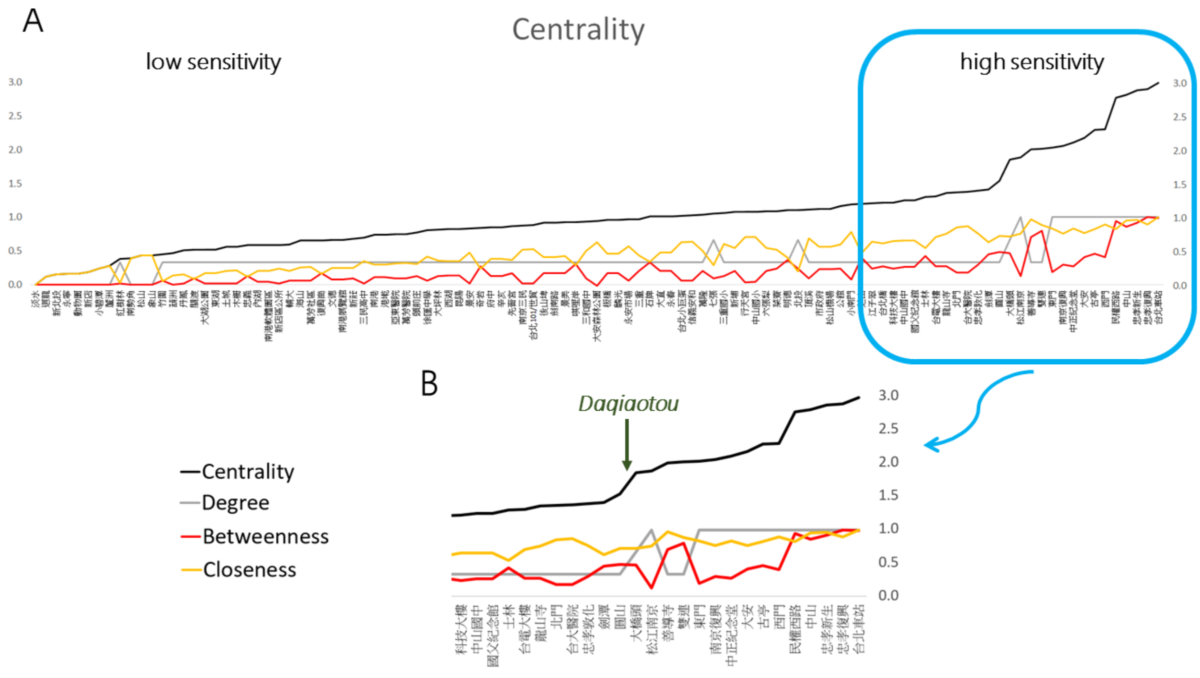

Figure 6 The centrality of each Station

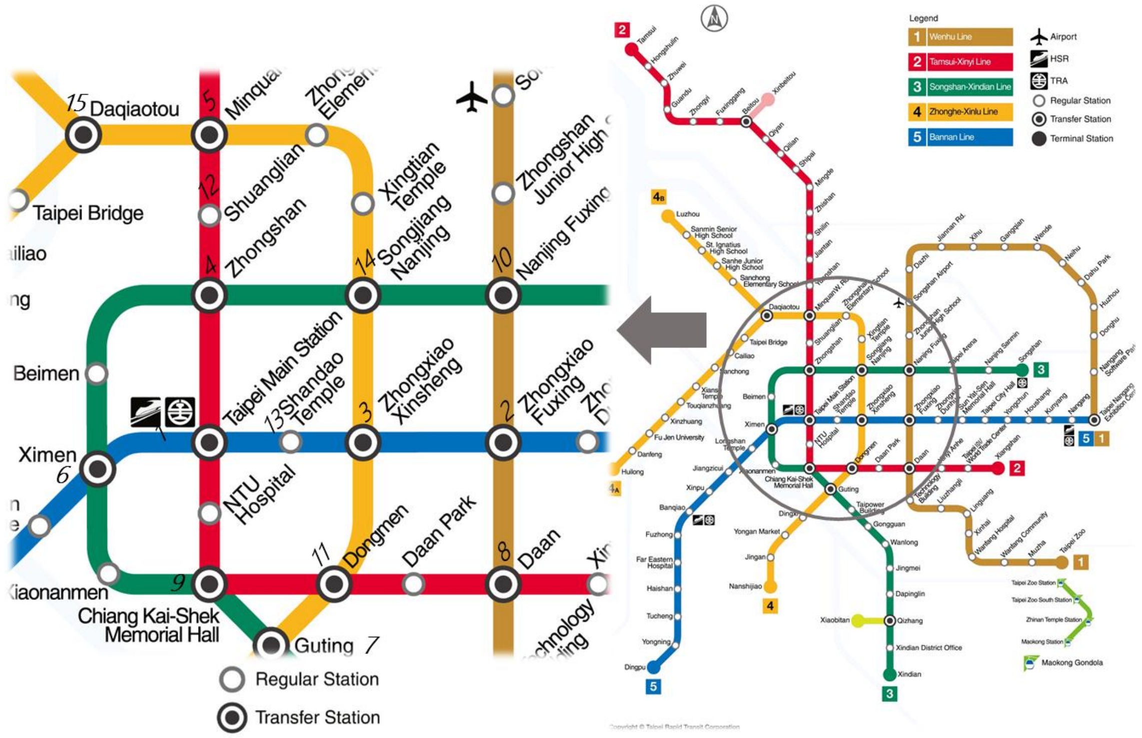

Figure 7 Map of Metro Taipei (Taipei Rapid Transit Corporation)

3.2 Exposure

At the beginning, we overlay the inundation scenarios map and find out it is a big question to deal with the risk. The risk from the ridership of a station is totally different from the inundation scenarios map. It's a problem to aggregate two different risk factor in the same scale. Therefore, we only take ridership of a station into consideration. We layout interior sensitivity on X axis and exterior exposure on Y axis. The ridership statistics highlight some periphery stations from their original group (Figure 8 red circle), such as Jiantan, Zhongxiao Dunhua, Taipei City Hall, Xinpu, Tamsui and Nangang station. These stations are not vulnerable in the whole network structure, but the ridership increase the vulnerability. In addition to those high sensitive station, these low sensitivity but high exposure stations are also significant to the network.

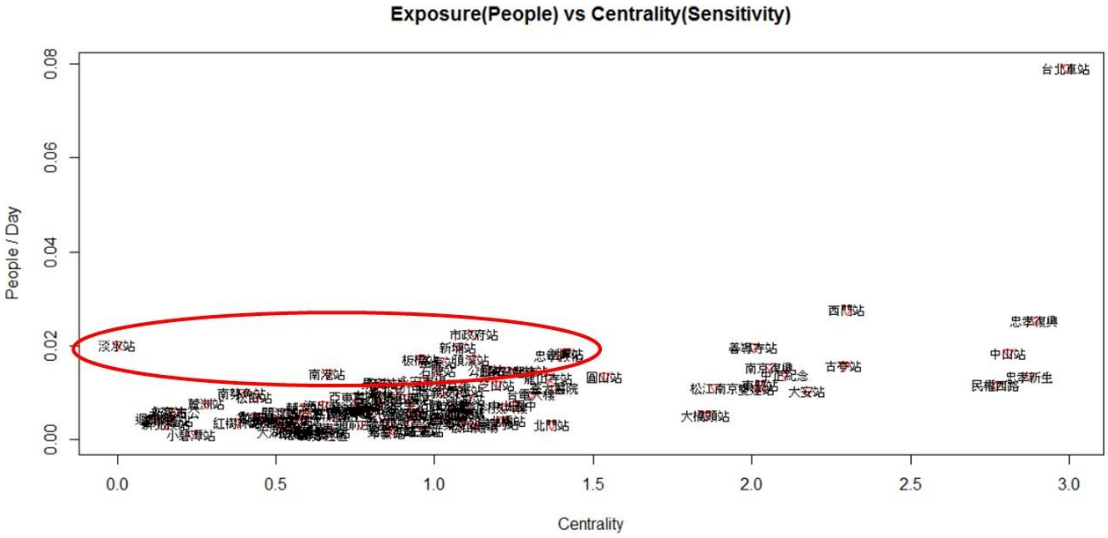

Figure 8 The diagram of exposure and centrality

3.3 Adaptability

We calculate the bus routes and public sharing bicycles around the station(Figure 9). Once an accident occur to the station, the surrounding alternatives play an important role to undertake the loading of ridership. Comparing with fifteen high sensitivity station, only four of them own sufficient alternatives. It may represent the adaptability of the Metro Taipei still need to improve in various way. The vulnerability still high in those important station, the network will remain an unstable situation. But in some region, such as WenHu Line (Line 1) and some stations near tourist attractions, these stations have certainly adaptability in the network. Due to numerous bus routes and public sharing bicycles, the trend of adaptability goes up at Jiantan and Taipei City Hall station. Especially the Taipei City Hall station are the public sharing bicycles' demonstration area, there are the biggest public sharing bicycles' shed in Taipei city.

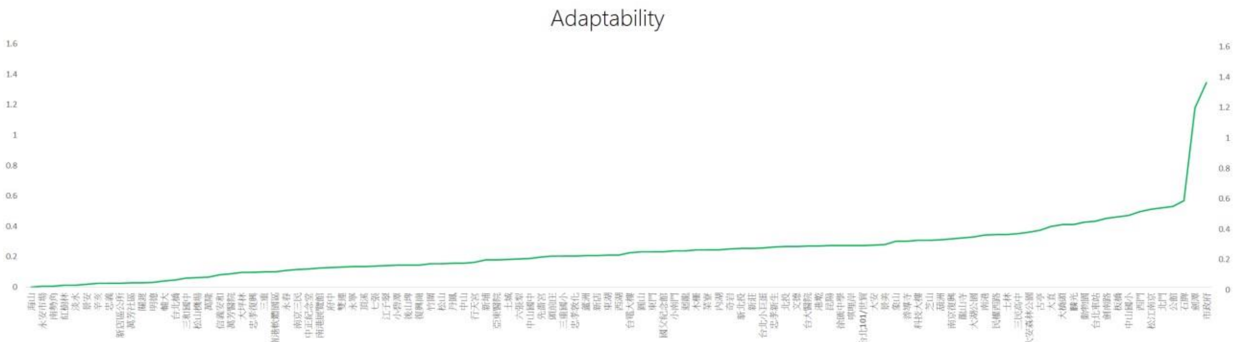

Figure 9 The Adaptability of each Station

3.4 Vulnerability model

The vulnerability model calculation assign to the individual station in Figure 10. The stations are symbolized with green, yellow and red symbol. High sensitivity stations stand in the urban region(Figure 10A). High exposure is related to the ridership of the station and they reflect those tourist spots and New Taipei City's residential area(Figure 10B). By aggregating sensitivity and exposure index, we reveal those high vulnerability station in Figure 10D. We symbolize the station's vulnerability with symbol size. The Figure 10D reveal those high connected transfer stations have higher vulnerability. We add adaptability into vulnerability model to turn into adjust vulnerability model(Figure 10E). The station with with green check means their adaptability index were higher than vulnerability index and their transport alternatives can undertake the ridership of the station when accident happen. Especially, the Taipei City Hall, Jiantan, Ximen, Banqiao, Gongguan, and Songshan station's vulnerability are well adjust by their adaptability.

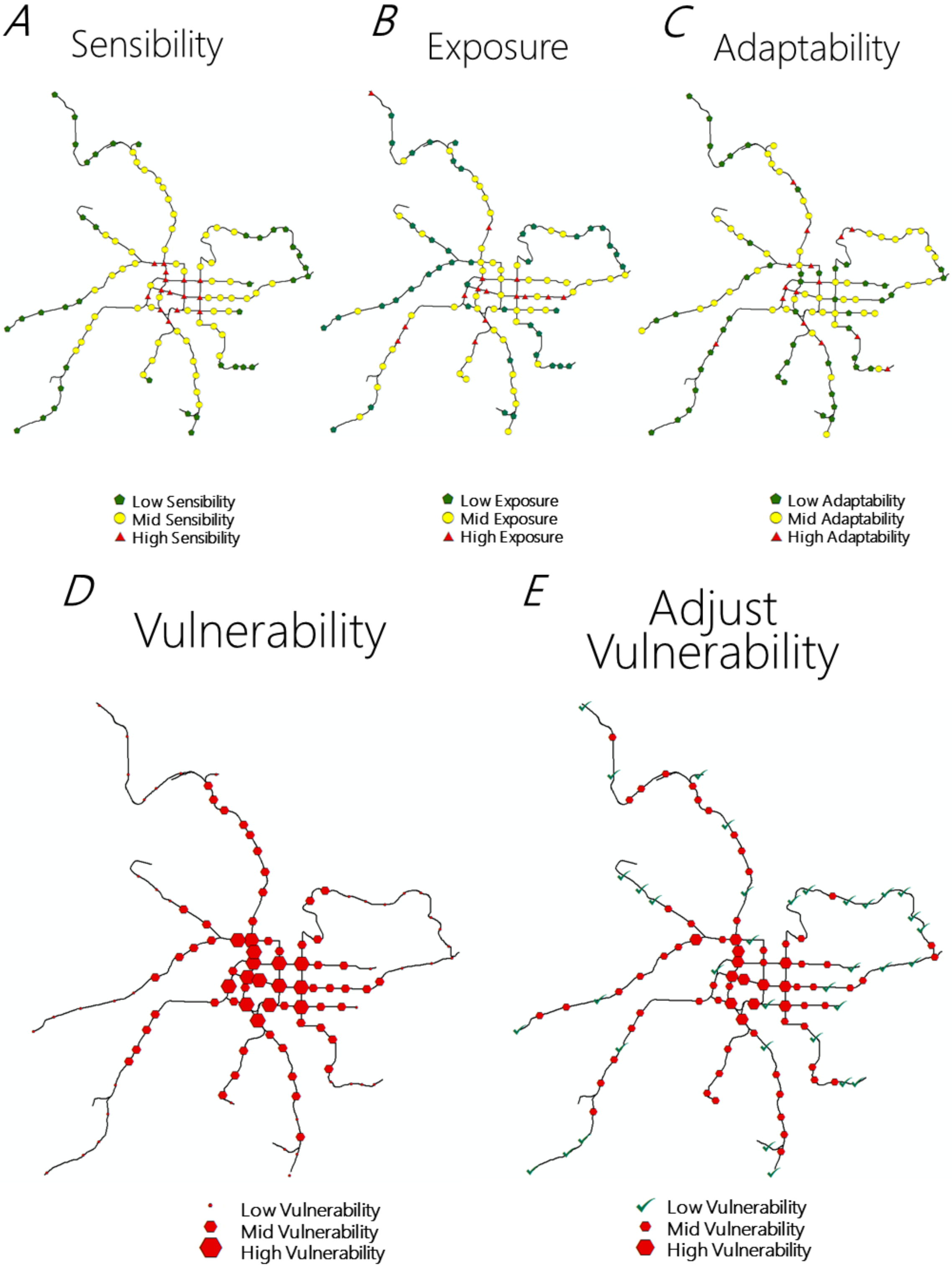

Figure 10 The Vulnerability Model

4. CONCLUSION and FURTHER RESEARCH

Our model can preliminary find out those high vulnerability station well. And group them into 3 different level, the authority can manage the station with this grouping standard. Those high fifteen sensitivity station, only four of them have sufficient adaptability (Table.1 in red below), once accident happened, the surrounding transport alternatives are unable to take care the ridership. And we recommend the Metro Taipei place the shuttle bus between those high vulnerability stations.

The Further Research can focus on using Metro Taipei suspended data, to simulating the real risk of each station. And we should take ripple effect in to consideration, because one station was suspended, the effect will spread out to whole network. And we can also use the public bicycle real time data, to increase the temporal resolution.

Table.1 Vulnerability Model

Vulnerability		**Adaptability**	
Taipei Main Station	0.5379	Taipei City Hall	0.6718
Zhongxiao Fuxing	0.4949	Jiantan	0.5897
Zhongxiao Xinsheng	0.4861	Shipai	0.2848
Zhongshan	0.4774	Gongguan	0.2662
Minquan W. Rd.	0.4676	Beimen	0.2614
Ximen	0.3972	Songjiang Nanjing	0.2559
Guting	0.3896	Ximen	0.2488
Daan	0.3678	Zhongshan Elementary School	0.2364
Chiang Kai-Shek Memorial Hall	0.3575	Banqiao	0.2315
Nanjing Fuxing	0.3506	Jiannan Rd.	0.2268
Shandao Temple	0.3442	Taipei Main Station	0.2163
Dongmen	0.3437	Taipei Zoo	0.2137
Shuanglian	0.3416	Linguang	0.2060
Songjiang Nanjing	0.3198	Daqiaotou	0.2055
Daqiaotou	0.3118	Dazhi	0.2002

5. ACKNOWLEDGMENTS

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6. REFERENCE

Corporation, T. R. T. (2016, 2016/4/6). Route Map. Retrieved from http://english.metro.taipei/ct.asp?xItem=1056373&CtNode=70241&mp=122036

Crucitti, P., Latora, V., & Porta, S. (2006). Centrality measures in spatial networks of urban streets. *Physical Review E, 73*(3), 036125.

Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social Networks, 1*(3), 215-239.

Guimerà, R., Mossa, S., A., T., & Amaral, L. A. N. (2005). The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. *Proceedings of the National Academy of Sciences, 102*(22), 7794–7799.

Porta, S., & Scheurer, J. (2006). *Centrality and connectivity in public transport networks and their significance for transport sustainability in cities.* Paper presented at the World Planning Schools Congress, Global Planning Association Education Network.

Rodríguez-Núñez, E., & García-Palomares, J. C. (2014). Measuring the vulnerability of public transport networks. *Journal of Transport Geography, 35*, 50-63.

Sussman, J. (2002). *Introduction to Transportation Systems*. Boston: Artech House.

Taaffe, E. J., Gauthier, H. L., & O'Kelly, M. E. (1996). *Geography of Transportation* (2 ed.): Prentice Hall College Div.