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APPLY ANALYTIC NETWORK PROCESS (ANP) TO ANALYZE THE DECISION FACTORS OF RELIEF RESOURCES ALLOCATION: A CASE STUDY IN TAIPEI STREET TREES RECOVERY IN POST-DISASTER

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Abstract

Typhoon is the most significant natural disaster in Taiwan.The Emergency Operations Center (EOC) make decisions aboutresources allocation for each city region based on damages happened in Post-disaster, to allocate relief resources to the optimal disaster stricken areas.Relief resources allocation is a Multi-Criteria Decision Making (MCDM) problem. The influence on the factors (criteria) of decision about disaster prevention and relief is urgent, varied and complex. We have to integrate all the opinions of decision makers in a very short time, in order to reach a final and effective decision making.The Analytic Network Process (ANP) matches multi criteria group decision making of disaster prevention and relief.In this study, a case study of street tree disaster recovery at Parks and Street Lights Office, Public Works Department, Taipei City Government (referred to as the Parks Office).We constructed a decision model of relief resources allocation through interview and discuss with the decision makers in EOC, which listed three dimensions and seven factors that influenced decision making.Those dimensions and factors can be compared through questionnaires.Analytic Network Process (ANP) is used to resolve the priority weights of factors and the order of importance. The result hasbeing applied to "Taipei City Street Trees and Park Facilities Mobile Patrol System - Disaster Reporting and Decision Support Subsystem" to produce recommendations allocation ratio of relief resources by district and road. Then provide decision supports for disaster relief commander and unit heads.

Keywords: Analytic Network Process (ANP), group decision, relief energy, resources allocation, Typhoon.

1. Introduction

Taiwan is located in the subtropical zone. Typhoon is the most frequently occurring natural disasters in summer also fall season. According to Central Weather Bureau statistics, the annual average of 3-4 typhoons hit Taiwan. With extreme weather caused by global warming and climate change,the level of typhoon is more powerful than ever before, and the scale of the disaster caused is more serious. Therefore, local government have the capability of emergency management is crucial.Emergency management consists of five phases: prevention, mitigation, preparedness, response and recovery. How relief commander in the case of a short time and under pressure to make effective prevention and relief decisions in each phase. It will have a great impact on the loss of people's property and lives.

When the Central Weather Bureau issued a typhoon warning, the government's Emergency Operations Center (EOC)is established immediately. According to disaster situation and existing relief energy, makingdecisions about the regional disaster relief resources allocation. After relief commander, deputy commander and decision aides carried out group decision making,allocating the relief energy (manpower, equipment, vehicles, etc.) to the optimal disaster stricken areas, that need to consider many factors. Such as disasters whether causing loss of citizens' properties, impact on traffic, the external pressure. Relief resources allocation is a Multi-Criteria Decision Making (MCDM) problem,and between the factors (criteria) are not usually exist independently, but affect each other. Relief decision with urgency, which have to integrate all the opinions of decision makers in a very short time, in order to reach a final and effective decision making. Under the best allocation of relief resources, improve disaster relief efficiency and shorten the process of involution, with a view to early resumption of the cityscape. Therefore, development of a group of multi-criteria decision model, for the decision support of relief resources allocation will have an absolute value and help.

Decision making of relief resources allocation is Multi-Attribute Decision Making (MADM). In order to achieve specific goal, need to assess the importance of each attribute, and listed in order of priority. MADM has been developed many methods. Wherein the Analytic Hierarchy Process (AHP) is Saaty (1980) developed a kind of multi-criteria group decision analysis method. [1]However, in the real world, a lot of decision making problems represented as hierarchy structure, that have characteristics of the interaction and dependent between the criteria. Therefore, Saaty proposed Analytic Network Process (ANP) in 1996. It improved shortcomings of AHP that between the criteria and levels are independent of each other. Added features of dependence and feedback between the criteria to meet the needs of actual decision making situations. [2] This method matches for Disaster Prevention and Relief relevant decision analysis.

In disaster risk assessment, prevention and disaster relief decision analysis, ANP method has been widely used in the assessment of the key factors that causing disaster risk, analyze the impact of disasters and choose the best solution of disaster recovery. Levy and Taji (2007) proposed in the case of having incomplete information, the application Group Analytic Network Process (GANP) to support disaster planning and disaster management. [3] Lai and Pai (2012) applied analytical network process to flood adaptation strategic planning,and stablishedseven assessment indictors that are suitable in urban level to calculate the weights of each indictor and optimal strategy plan. It will provide some principles and strategies for future spatial planning and disaster management policies for governments. [4] Wu et al. (2014) proposed an intelligent slope disaster prediction and monitoring system based on WSN (Wireless Sensor Networks) and ANP. To analysis various factors of hillside disasters, and established a decision-making model through ANP method. Collecting a variety of data returned from wireless sensors installed on the slopes. To sum up the returned data and corresponding assessment criteria's weights, which used to determine and forecast whether the hillside is upcoming danger. [5] Chen, Wey, and Chang (2014) proposed Fuzzy Delphi method (FDM) and ANP technique, integrate experts' opinions. To estimate the disaster resilience in redeveloped area of Tamsui river basin(Taiwan). Through assessment of the impact of 5 dimensions and 13 criteria (resilience index), to analysis the 5 top priority resilience indicators,that can provide a reference for the future development in the region. Government could follow indicators efficiently allocate regional resources,as to reduce the severity of disasters. [6] Asadzadeh, Kötter, and Zebardast (2015) use factor analysis and analytic network process (F'ANP) to calculate the weights of disaster resilience indicators. By calculating and aggregating the scores those in the 22 urban regions of Tehran, Iran. Finally, it generated a disaster resilience index (DRI) to measure the ability of each regions to recover from earthquake hazard [7]. The influence on the factors (criteria) of decision about disaster prevention and relief is sudden, varied and complex. ANP method is very suitable for use in disaster prevention and relief management. Therefore, this study apply Analytic Network Process (ANP) to help decision support of street trees relief resources allocation in Post-disaster. To explore the factors that may have influence on the decision-making, andhow to work upon each other among multiple criteria. And to calculate the priority weight of factors and the order of importance,that can help government to setting priority weight of evaluative factors in disaster decision support system. In this paper, the construct and calculate steps of ANP method will present in the chapter 2. In the chapter 3, a case study in Taipei street trees recovery in Post-disaster. That apply Analytical Network Process (ANP) to analyze the decision factors of relief resources allocation. The results, the important of factors and the relationship between factors will be discussed in the chapter 4.Finally, the conclusion, in the chapter 5, will summarize results of this study and propose the possible research in the future.

2. Analytic Network Process (ANP)

ANP method is improved AHP method hierarchical structure to network structure. Added two characteristics that are dependency of factors in same level and feedback in different levels of hierarchy. AHP hierarchy structure can be said to be a special case of ANP network structure. The following will describe the required steps of analysis and calculations when use ANP to solve complex decision making problems.

2.1 To Compose a Decision Making Group and Construct a Network Structure Diagram

A dicision making group is composed of revelent decision makers, to define decision making problem that is needed to be solve. First, the goal must be clear and simple, as to solve a simple decision making problem. Then, deciding the evaluation dimensions to reach this goal. Each dimension contains a number of the same type of influence criteria. Finally, to construct a network structure diagram.

2.2 Questionnaire Design and Survey

Design questionnaires according to network structure diagram. Each element according to the upper element or elements of the same dimension, pairwise comparison between the elements by members of the decision group. ANP used the same evaluate scale as AHP, used 1-9 ratio scales proposed by Saaty. After the design of the questionnaire is completed, you can send it to members of group decision to investigate.

2.3 Construct Pairwise Comparison Matrix and Group Decisions Integration

The comparisonbetweenfactors based on different level that will generate a pairwise comparison matrix (A). The pairwise comparison matrix is positive reciprocal matrix. As shown in Formula (1), w_i is the weight of element i (i=1,2,3,…,n).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

To integratethe judgements of R experts, in order to construct an integrated pairwise comparison matrix. Saaty recommend using the geometric mean method to integrate the judgement results of different decision makers [1], as shown in Formula (2). When there are n elements for judging important, a_{ij} is weight of the element i compare to the element j, h is the number of members of the decision making group.

$$a_{ij} = \left(\prod_{h=1}^{R} a_{ij}^{h}\right)^{\frac{1}{R}}, \quad i,j = 1,2,\dots,n \quad (2)$$

After pairwise comparison matrix is completely integrated, it can calculate the eigenvector and the maximum eigenvalue (λ_{max}) for each pairwise comparison matrix. Saaty proposed four method of approximation to calculate eigenvector. In this study, that use Normalization of the Geometric Mean of the Row (NGM) method. As shown in Formula (3), multiplied each row element and calculate geometric mean. Then normalized to obtain eigenvector W_i. Finally, calculated λ_{max}, as shown in Formula (4). Pairwise comparison matrix (A) by multiplying the eigenvectors (W), can obtained a new eigenvector (W'). Then each value of vector W' is correspond divided by the original value of vector W respectively. Finally, to calculate the arithmetic mean form each value, it can obtain λ_{max}.

$$W_i = \frac{\sqrt[n]{\left(\prod_{j=1}^{n} a_{ij}\right)}}{\sum_{i=1}^{n}\sqrt[n]{\left(\prod_{j=1}^{n} a_{ij}\right)}}, i,j = 1,2,\dots,n \quad (3)$$

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i} \quad (4)$$

2.4 Consistency Test

The judgment of decision makers on paired elements have to satisfy the transitive property. It must be approved by the consistency test, and testing the judgement of experts whether having consistency. It use Consistency Index(C.I.) to mesure, as shown in Formula (5). When comparing n elements, C.I.=0 means fully consistency, C.I.>0.1 means inconsistency. Saaty (1980) suggests C.I.≦0.1 is the acceptable range.

$$C.I. = \frac{\lambda_{max} - n}{n-1} \quad (5)$$

The ratio of C.I. and Random Index (R.I.) is Consistency Ratio (C.R.). as shown in Formula (6). R.I. value is obtained from Table 1. When C.R.<0.1, the matrix satisfied consistency check, showing the pair scale has a certain degree of reliability.

$$C.R. = \frac{C.I.}{R.I.} \quad (6)$$

Table 1 Random Index

n	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Note. From Saaty（1980）

2.5 Supermatrix andWeight of Criteria

ANP method using supermatrix to calculate the weights. First, the dependency relationship between different elements which is a submatrix. The submatrix is composed of eigenvectors that compared with each elements. The unweighted supermatrix is composed of these pairwise comparison matrix. As shown in Formula (7), C_m represents m dimension, e_{mn} represents n criteria of m dimension. W_{ij} represents the eigenvectors of between i dimension and j dimension. If dimensions aren't affecting each other, then $W_{ij}=0$. And then, unweighted supermatrix shall be converted to weighted supermatrix that is column-stochastic,and column-stochastic means that the sum of each column of the matrix is 1. Finally, after the limiting process to obtain the limited supermatrix. As shown in Formula (8), after the matrix multiplied k times by it self, until the weight of each column in the matrix converges to same value. Thefinal result of supermatrix after the operation is the relative weight of each criteria,that reprented the importance of criteria in decision making.

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11}\cdots e_{1n_1} & e_{21}\cdots e_{2n_2} & \cdots & e_{m1}\cdots e_{mn_m} \end{array} \\ \begin{array}{c} C_1 \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots \\ C_n \begin{array}{c} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{bmatrix} \end{array} \quad (7)$$

$$\lim_{k\to\infty} W^{2k+1} \quad (8)$$

3. Case Study

3.1 Background

In August 2015, SOUDELOR typhoon hit Taiwan. In the course of the typhoon landed, bringing strong winds and heavy rain to Taipei. Instant 13 strong wind caused the city a large number of street trees dumping disaster. There were trees broken down the middle, dumping and skew on the streets everywhere. Statistics EOC of Taipei City Government Fire Department received notification street trees poured a total of 3,282 cases, of which 6,560 trees all down trees, dumping 2,801 trees, snags 10,933 trees, a total of 20,294 trees damaged. This typhoon is the most number of street trees disaster cases in recent years[8]. After the typhoon disaster, EOC deployment of human equipment, to master control rehabilitation schedule, coordinating the operation of the units. The relevant units of the City Government have invested a lot of manpower and equipment to clean street trees. Although mobilize all human and material resources to recovery cityscape, the public still questioned government inefficiency in disaster relief, recovery is slow in Post-disaster. It caused people complaining and poor perception.

3.2 Research Design

In this study, a case study of decision factors in relief resources allocation at Parks and Street Lights Office, Public Works Department, Taipei City Government (hereinafter referred to as the Parks Office) EOC team Post- disaster. Applying ANP method to analysis and comparison of the relative importance of factors that affecting disaster resources allocation. Hope to draw past hurricane experience of decision makers in EOC. In order to improve disaster relief mechanisms and methods. To faster recovery of cityscape in future typhoon disaster.

3.2.1 To Compose a Decision Making Group and Construct a Network Structure Diagram

Group decision members served as relief commander, decision aid, or disaster relief unit head. To assess the dependence between the factors, thatneed to collect opinions through groups. Throughinterviews with experts to learn case processing and factorsthose may affect relief resourcesallocation at EOC. To evaluate and analyzeeffectively, the study was discussed with the EOC members at the Parks Office,establishing a path to reach the goal of assessment about decision factors of streettreesdisaster resourcesallocation in Taipei city, and find dimensions and factors those affecting the disaster relief resource allocation. Description of assessment dimensions andassessment factors is shown in Table 2.

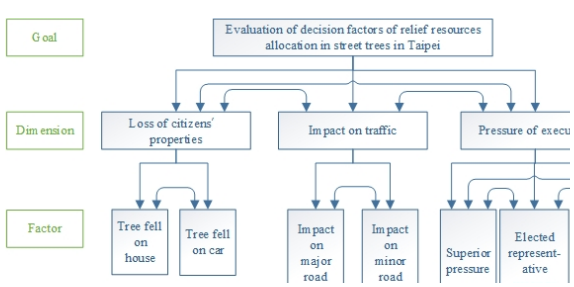

Figure 1 ANP network structure diagram

Table 2 Description of Assessment Dimensions and Assessment Factors

Dimension	Factor	Description
Loss of citizens' properties	Tree fell on house	Trees fell on the people's house, that cause people's lives is not convenient, needed the Repair Team of the Parks Office to remove the trees, in order to carry out repairs.
	Tree fell on car	Trees fell on car parked on roadside should be off the field for maintenance after the Repair Team of the Parks Office to remove the trees.
Impact on traffic	Impact on major road traffic	Trees fell on the major road, that impact the traffic smoothly.
	Impact on minor road traffic	Trees fell on the minor road, that impact the traffic smoothly.
Pressure of execution	Superior pressure	Including the higher the rank of chief at Parks Office, the Public Works Department or the higher level executive of the government, given the pressure through direct instructions.
	Elected representative pressure	Including elected representative through parliamentary interpellation or notice, or head of village call directly to ask deal with as soon as possible.
	Media report	Various television stations, newspapers or internet media report extensively put pressure on the time course of relief.

After affected dimensions and factors are established, using dependence and feedback to build ANP network structure diagram, as shown in Figure 1. In this study, using Super Decisions software version

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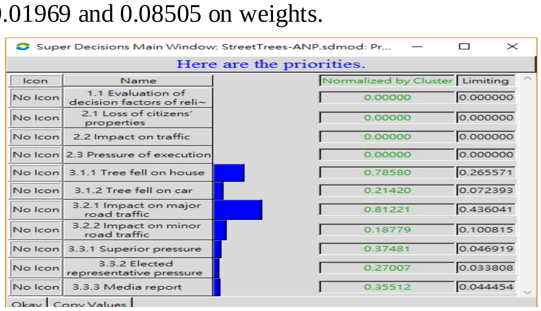
2.8.0(www.superdecisions.com) to draw network structure diagram,useing arrow symbolic to link goal, dimensions and factors to represent the correlation between the elements, that dependency and feedbackrelationship.

4. Result and Discussion

The prioritiesfunction of Super Decisions can generate weight of assessment criteria under dimensions through the calculated result out of the limit of the supermatrix,and the weight of overall evaluation criteria after the limit of regardless of dimensions, as shown in Figure 2.The result showed that the weight of tree fell on house (0.7858) is greater than tree fell on car (0.2142) under the loss of citizens' properties dimension.It represents that as estimate relief resources allocation, if we encounter situations like loss of citizens' properties, tree fell on house is prior to tree fell on car, that has priority to dealing with.Under the impact on traffic dimension, the weight of impact on major road traffic (0.81221) is greater than the minor road traffic(0.18779),that indicates the priority need to remove the major road obstruction, then processing minor road section for the traffic smooth recovery. Under pressure of execution dimension, the first priority is superior pressure (0.37481),followed by media report (0.35512), the last iselected representative pressure (0.27007).But there are little differences between the importance of these three pressure of execution, and with only differences of 0.01969 and 0.08505 on weights.


Super Decisions Main Window: StreetTrees-ANP.sdmod: Pr...

Here are the priorities.

Icon	Name	Normalized by Cluster	Limiting
No Icon	1.1 Evaluation of decision factors of reli~	0.00000	0.000000
No Icon	2.1 Loss of citizens' properties	0.00000	0.000000
No Icon	2.2 Impact on traffic	0.00000	0.000000
No Icon	2.3 Pressure of execution	0.00000	0.000000
No Icon	3.1.1 Tree fell on house	0.78580	0.265571
No Icon	3.1.2 Tree fell on car	0.21420	0.072393
No Icon	3.2.1 Impact on major road traffic	0.81221	0.436041
No Icon	3.2.2 Impact on minor road traffic	0.18779	0.100815
No Icon	3.3.1 Superior pressure	0.37481	0.046919
No Icon	3.3.2 Elected representative pressure	0.27007	0.033808
No Icon	3.3.3 Media report	0.35512	0.044454

Okay | Copy Values

Figure 2. The weight of each assessment criteria on goal

The weight and ranking for each dimensionand factorcan be learned according to the limit of the supermatrix.In order to achieve disaster resources allocation decision for street trees in Taipei,as ifadding up weights of factors under dimensions to present the importance of the dimensions,the weight of impact on traffic is accounted the most weight, which expressed trafficis the highest priority task for in Post-disaster recovery.It must first allocate relief resources to remove obstruction caused by street trees,in order to avoid affecting the people commute to work and refrain from inconvenience.The dimensions of loss of citizens' properties(0.338) is the second most important,as this involves the loss of citizens' properties,then the loss may get worse if not handle as soon as possible, and derivetheproblemof state compensation.The pressure of execution(0.125) is relatively unimportant factor, and caused only a slight impact for decision on allocation of relief resources.

To add up the two dimension factors right before, the result are accounted for 87.5% of all the factors,that represents individual decisionmaker can perform relief according to the actual disaster in the face of external pressure of execution.And add up the total external pressure is accounted for only 12.5% of all the factors, that showedexternal pressure has less influenceon decision maker.All of them have good resistance to pressure, including relief commander, decision aides, and relief unit heads. Superior is the main source of pressure for

The overall disaster situation should be considered when allocate the resources,as far as possible without external pressure, so as not to disrupt the proress for relief work, and causing uneven resources allocation and waste,resulting ininefficiency recovery in Post-disaster.

5. Conclusion

Reliefresources allocation is a difficult decision problem, among factors of influence usually have interdependent features. It is difficult to judge between what factors influence each other.A number of decision-makersusually take up the position of relief commanderwithround-the-clock shifts.The different decision-makers inevitably have subjective judgment about the problems, leading to inconsistency on allocation of relief resources. Group decision will help to determine the degree of dependence between the factors. ANP is very suitable to analyze the interdependence of decision factors of relief resources allocation. Finally, the integration of the opinions of group, through the operation result of supermatrixto show the importance of the weight of each factor. So as to uniform allocation of disaster relief resources scheduling and management with the damage and relief progress bythe consistency in factors weighted standard.

This study uses ANP analysis on the factors of street treesreliefresources allocation decisions at the Taipei City Government Parks Office,and explores the relationship and the important degree of factors. The results of this study show the weight of decision-making factors of influence on relief resources allocation that will be provided to EOC commander of Park Office as decision making, And being applied to "Taipei City Street Trees and Park Facilities Mobile Patrol System - Disaster Reporting and Decision Support Subsystem". This system isa cloud-based mobile intelligent disaster prevention decisionmaking system.For disasterinformationcollection, suggestions use big data or Text Mining technology in future, analyzing the open data about cases of the EOCof Taipei City Government Fire Department during disaster period. The actual disaster about damage tree is presented in a way to quantify, with the weight value that influent relief resources allocation factors, to enhance the efficiency of disaster relief .

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