Assessing the Influential Factors of Fire Rescue Using DEMATEL Method

Chun-Kai Yang, Bing-Jean Lee, Tsu-Chiang Lei, and Lanasari

***Abstract*—The objective of this study was to identify main factors that influence fire rescue. In focusing on the purpose of this research, a decision-making trial and evaluation laboratory (DEMATEL) was implemented to establish a network relation map (NRM), which afterward was employed to illustrate the influential network of factors related to fire rescue. The results showed that the water supply allegedly is recognized as a major key which has the most influence on other dimensions. This improvement model is useful in establishing an influential network and a prioritization among dimensions/criteria associated with fire rescue.**

***Index Terms*—Fire rescue, DEMATEL (decision-making trial and evaluation laboratory), NRM (network relation map).**

I. Introduction

Nowadays, society and ecosystem have been in a great transition. Urbanization and industrialization have changed the society into a very pluralistic society with different lifestyles. The changes because of human activities also affect ecosystem around the globe which led to widespread or enduring consequences [1]. The consequences are a wide range of environmental disasters. One of them is fire, which has become such social and physical phenomena that bring fear to people [2].

Fire can be destructive, tearing apart families, destroying homes and polluting the air by releasing carbon dioxide which harmful to human health. According to Geneva Association survey, some industrialized countries had suffered between 0.04 to 0.22 percent of GDP [3]. Fire has been a major threat to human life and property, affecting humans in different ways [4]. It has an impact on air quality [5], [6], environment [7], [8], society [9], [10], and economic [11], [12] which brings suffering harm and loss.

In Taiwan, fires kill hundreds of people and destroy billions of dollars of worth properties every year [13]. In order to extinguish the fire, prevent casualties, and avoid property damages, fire department plays a very important role in fire rescue. Fire departments also provide many services within the community, such as fire suppression, emergency medical services, technical rescue, and fire safety education. In other words, fire departments have a direct and significant impact on the effectiveness of fire rescue service.

However, past experiences of other countries and relevant research about fire rescue indicated that there are quite complex multifaceted factors which affecting the performance of fire rescue. Conducive to effectively evaluate the occurrence of fire rescue and influential factors related, this research applies DEMATEL (decision-making trial and evaluation laboratory) method to discover the influential degree among factors and to facilitate public sector with improvement solutions based on those priorities.

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II. Literature Review

Fire rescue is an operation of firefighting in the event of fire with purpose of reducing the loss of life and property. When many people think of the fire rescue service, what comes to mind is the response aspect of the work – reacting to emergencies, putting out fires or saving lives that are in danger. Firefighters have done a lot of contribution in fire rescue service. They even sacrifice themselves for the sake of others. There are many firefighters lose their lives or injured in the line of duty each year [14]. As the fire rescue is an extremely complex operation with a variety of subjective and objective factors involved that caused the fire rescue process consistently difficult to do. Thus, it is very crucial for people around the world to plan and implement the fire rescue carefully, to identify and understand the factors that influence and have impact on overall fire rescue service.

Fire rescue requires a complex and efficient system [15]. There are many factors that play important role in fire rescue to be successfully operated. These include general information about fire, fire department, equipment, training, communication, information, water supply, fire rescue team and teamwork, etc.

Firefighters are one of most important elements in fire rescue service. Particularly, Cote and Bugbee [16] stated firefighters as the significant resource to fight the fire. Fire rescue needs competent team to do its operation, including a competent fire commander who can manage and use available resources effectively and efficiently to fight the fire, protect life and property. Besides, it is crucial for firefighters to know the command structure because it is critical to keep the incident information up to date, so the commander can come up with the safest way to deal with the situation. Technical skill, physical strength, and personal commitment are indeed vital for the firefighters as well. Nevertheless, the foremost skill or attribute for firefighters is the ability to work together with others as part of a coordinated team.

Fire rescue also needs fire equipment which is basic support of its service to extinguish the fire. Whether it's your home or office, it’s always good to have firefighting equipment with you, and more importantly know how to use it. As for water supply, it is absolutely very critical to assist the fire rescue operation. Water is the major substance used to control the fire. Water supply is essential even if you do not have any installed fire protection systems; it becomes even

more crucial if you do. In addition, all information about fire, fire rescue team, equipment, water supply in the area provides a database of information that can be used during a fire rescue operation or afterward as an evaluation.

Based on comprehensive literature reviews [17]-[20], this research explores related factors to fire rescue into 5 dimensions: equipment, command and control, water supply, personnel training, and information services. Understanding the key factors of fire rescue will identify emerging issues, reduce the risk, enhance performance and improve the effectiveness. The purpose of this research is to provide an evaluation of fire rescue to impress the fire risk perceptions and to increase attention and awareness on fire rescue problem.

III. Research Method

The DEMATEL method is generally used to encounter the intertwined and complex problem with many factors involved. It is employed to discover the influence of each factor and influential relations among them.

A. Data Collection

The list of factors that related to fire rescue was determined based on literature reviews and brainstorming by experts as displayed in Table I. Those factors include 5 dimensions and 15 criteria. A questionnaire was designed with responses ranged by measurement scale from 0 to 4 that show the influential degree among dimensions and criteria. In this research, the questionnaire was completed through personal interview of fire department personnel, such as commissioner, chief, fire commander, and firefighters.

B. DEMATEL Method

This study implemented the DEMATEL method to analyze the interrelation among factors and compile the result into an apprehensible structural system and construct a network relation map (NRM) [21]. This method used matrix calculations to confirm all of the direct and indirect influential relations, as well as the impact strength. Then, the influential relation and influential degree among dimensions and criteria was displayed through a visual structural matrix and influence diagram. Finally, it was used to assist decision makers with a visual model illustrated by NRM that can be utilized to figure out the main problem and determine the influence and interrelation among factors.

The DEMATEL method process can be recapitalized in following steps:

1) Step 1: Calculate the average matrix

Let W experts and n criteria as consideration in this research. For the h^{th} expert, the pairwise comparisons between criterion i influences criterion j can be symbolized by p_{ij}^h. The evaluation value was given in range of 0, 1, 2, 3 and 4, representing 'no influence (0), 'low influence (1)', 'medium influence (2)', 'high influence (3)' and 'very high influence (4)', correspondingly. The values given by each expert provide a result of matrix $P^h = [\, p_{ij}^h \,]$, with $1 \le h \le W$. Then, compute the $n \times n$ average matrix D for all expert opinions by averaging the W experts' value as formulized below:

$$d_{ij} = \frac{1}{W}\sum_{h=1}^{w} p_{ij}^h \tag{1}$$

The average matrix $D = \left[d_{ij} \right]_{nxn}$, also known as the initial direct-relation matrix D, shows the initial direct influences which a factor exerts on and receives from other factors.

2) Step 2: Compute the normalized initial direct-relation matrix

The initial direct influence matrix A (i.e., $A = [a_{ij}]_{nxn}$) can be obtained by normalizing the average matrix A in the following formula.

$$A = D / v \tag{2}$$

$$v = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} d_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} d_{ij} \right) \tag{3}$$

3) Step 3: Determine the total relation matrix

A continuous decrease of an indirect effect of problems along with power of matrix A and the use of Markov chain skill are used to define the total relation matrix. The total relation matrix T is a $n \times n$ matrix and is derived as follows:

$$T = A + A^2 + \ldots + A^m = A(I - A)^{-1} \tag{4}$$

Then, the vector $\boldsymbol{x}$ and $\boldsymbol{y}$ are defined by calculating the sum of row and sum of column from the matrix T using equation (5) and (6) as follows:

$$x = \left[x_i \right]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij} \right)_{n\times 1} \tag{5}$$

$$y = \left[y_j \right]'_{1\times n} = \left(\sum_{i=1}^{n} t_{ij} \right)'_{1\times n} \tag{6}$$

where the superscript " ' " denotes transpose process.

TABLE I: Factors Related to Fire Rescue

Dimensions	Criteria
Equipment (D_1)	Complete equipment (C_{11})
	Proper equipment (C_{12})
Command and control (D_2)	Commander (C_{21})
	Officer (C_{22})
Water supply (D_3)	Natural water access (C_{31})
	Hydrants access (C_{32})
Personnel training (D_4)	Knowledge (C_{41})
	Rescue skills (C_{42})
	Physical condition (C_{43})
	Quantity (C_{44})
	Safety (C_{45})
Information services (D_5)	Reporting process (C_{51})
	Dispatch process (C_{52})
	Data record (C_{53})
	Feedback (C_{54})

The x_i represents the sum of i^{th} row in total relation matrix T. It displays both direct and indirect total effects given by criterion i to the other criteria. The y_j shows the sum of the j^{th} column in matrix T. It indicates the total effects received by criterion j from the other criteria. When $j=i$, the sum of (x_i+y_i) illustrates an index total effects of both given and received by

criterion *i*. Additionally, the $(x_i - y_i)$ denotes the contribution of criterion *i* net effect to the system. When the index of $(x_i - y_i)$ is positive, the criterion *i* is a net causer. Contrarily, when the index $(x_i - y_i)$ is negative, the criterion *i* is a net receiver.

IV. Analysis and Results

The evaluation of main influential factors in fire rescue service had become an important consideration for management scholars in assessing the effectiveness of fire rescue. Further, there are so many causes of fire which are complex. It is very important to have all knowledge and information needed, so fire department can properly manage an adjustable structure of fire rescue operation system by utilizing equipment and manpower. Additionally, fire department needs a well-managed fire rescue team with flexible arrangements that can fully operating and accomplish the mission. Therefore, the intelligibility of a fire department in implementing related factors is so critical to bring out the successful outcome.

When it comes to fire rescue, fire is identified based on the fuels involved in the ignition of the fire. The National Fire Protection Association (NFPA) categorizes fire into 5 classes [22]. This study focused on the most common class of fire and the DEMATEL method was applied to figure out the influential relations among factors associated with fire rescue.

A. Constructing NRM

This study used DEMATEL to define the initial direct-relation matrix and further normalized matrix $\boldsymbol{A}$ (as shown in Table II), then calculate the total relation matrix $\boldsymbol{T}$ (Table III). The consistency test showed high consistency ratio of 95.19% which indicates that the result is significantly dependable. The values of interrelation between dimensions and criteria are shown in term of $(x_i + y_i)$ and $(x_i - y_i)$ as shown in Table IV. This result allowed us to construct NRM as illustrated in Fig. 1. When $(x_i + y_i)$ is high and $(x_i - y_i)$ is positive, it can be defined that the particular criterion has most influence which in turn become a major factor to be concerned about. In contrast, when $(x_i + y_i)$ is high and $(x_i - y_i)$ is negative, then it means that a particular criterion is clearly be influenced by other criteria.

The NRM displayed that the influential degree can be sequenced based on high to low priority as $D_3 \succ D_1 \succ D_4 \succ D_5 \succ D_2$. This showed the existence of network relation between dimensions and each criterion within in fire rescue framework.

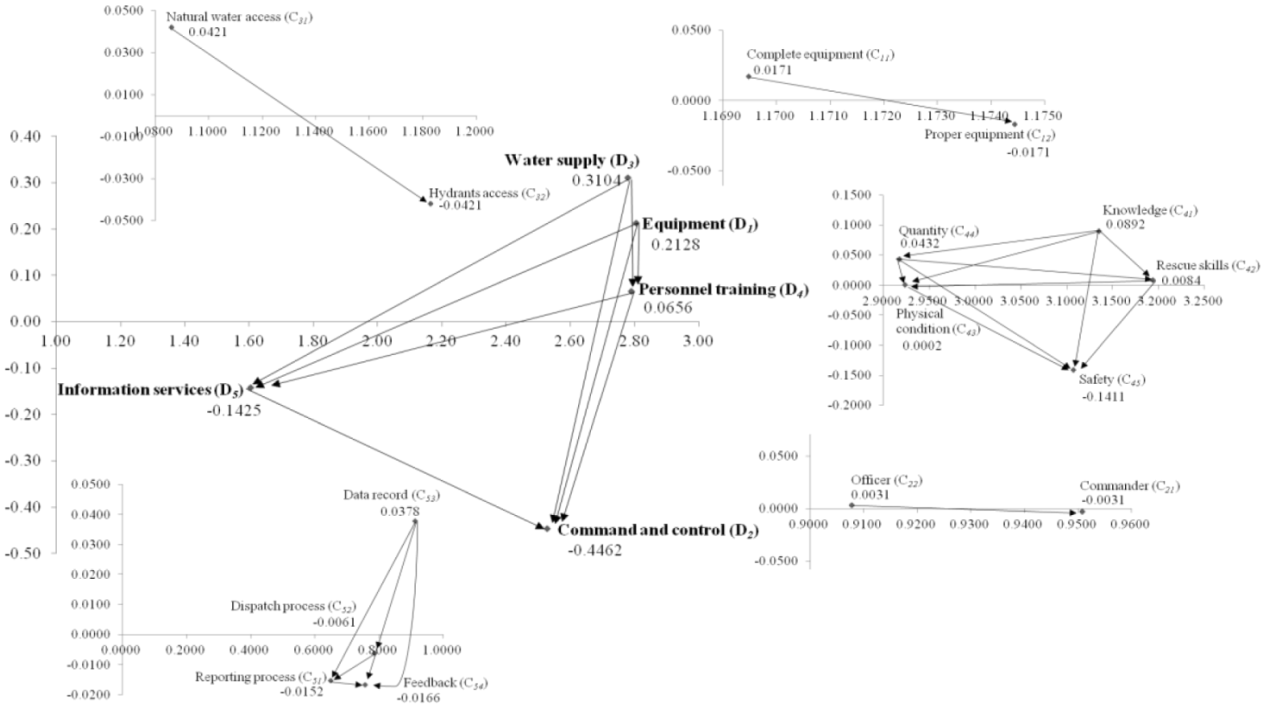

Fig. 1. Network relation map.

The result in this study showed that water supply (D_3) has the most impact on remaining dimensions. Each dimension and criterion contributes to the fire rescue problem. For example, commander and officer need to know all information needed so they can manage the operation and choose the best method to minimize the damage. Then, commander and firefighters work together to fight the fire with equipment required. However, even with adequate information, well-trained firefighters, competent commander, and complete equipment, fire rescue operation would not work without sufficient water supply.

V. Conclusion

Fire rescue is one of major tasks to accomplish in a fire department. There are many factors involved in fire rescue operation process that affect its performance and determine the success or failure of an overall operation. Thus, it is indispensable to evaluate and analyze those factors to obtain an appropriate fire rescue method and improve it to become more effective. This study applied DEMATEL method to construct an influence relations system which can provide a

profound evaluation for improvement of the fire rescue service according to influential level among factors related. However, this study only focused on a common class of fire and might inappropriate to apply it on other class of fire. The outcome from this study can be used as consideration and scope for further studies.

TABLE II: NORMALIZED MATRIX *A*

	C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{51}	C_{52}	C_{53}	C_{54}
C_{11}	0	0.08	0.09	0.07	0.03	0.07	0.08	0.10	0.09	0.08	0.08	0.07	0.07	0.05	0.05
C_{12}	0.09	0	0.10	0.07	0.03	0.08	0.09	0.09	0.08	0.05	0.07	0.08	0.08	0.05	0.03
C_{21}	0.05	0.05	0	0.08	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.08	0.05	0.05
C_{22}	0.04	0.05	0.07	0	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.07	0.07	0.05
C_{31}	0.07	0.09	0.09	0.08	0	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.03	0.07	0.05
C_{32}	0.09	0.09	0.10	0.08	0.08	0	0.08	0.07	0.08	0.08	0.07	0.03	0.03	0.07	0.05
C_{41}	0.06	0.07	0.07	0.07	0.08	0.08	0	0.10	0.08	0.08	0.10	0.03	0.03	0.05	0.05
C_{42}	0.08	0.07	0.08	0.07	0.08	0.08	0.10	0	0.07	0.07	0.10	0.03	0.03	0.04	0.04
C_{43}	0.07	0.08	0.07	0.07	0.08	0.08	0.05	0.08	0	0.08	0.09	0.03	0.03	0.03	0.03
C_{44}	0.07	0.06	0.07	0.08	0.08	0.08	0.08	0.07	0.08	0	0.08	0.03	0.03	0.03	0.03
C_{45}	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.07	0.08	0	0.03	0.03	0.03	0.03
C_{51}	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0	0.03	0.03	0.03
C_{52}	0.03	0.03	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0	0.03	0.03
C_{53}	0.03	0.03	0.08	0.07	0.05	0.05	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0	0.03
C_{54}	0.03	0.03	0.03	0.03	0.05	0.05	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0

TABLE III: TOTAL RELATION MATRIX *T*

	C_{11}	C_{12}	C_{21}	C_{22}	C_{31}	C_{32}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{51}	C_{52}	C_{53}	C_{54}
C_{11}	0.25	0.34	0.39	0.35	0.25	0.34	0.35	0.37	0.34	0.33	0.35	0.20	0.24	0.24	0.21
C_{12}	0.32	0.25	0.39	0.34	0.24	0.33	0.35	0.36	0.32	0.29	0.34	0.21	0.24	0.23	0.19
C_{21}	0.21	0.23	0.21	0.26	0.18	0.23	0.23	0.24	0.22	0.22	0.24	0.12	0.19	0.18	0.16
C_{22}	0.20	0.22	0.27	0.19	0.18	0.22	0.22	0.23	0.21	0.21	0.23	0.12	0.18	0.19	0.16
C_{31}	0.32	0.35	0.39	0.35	0.22	0.34	0.34	0.35	0.33	0.32	0.35	0.16	0.20	0.26	0.21
C_{32}	0.34	0.35	0.40	0.36	0.30	0.27	0.34	0.35	0.33	0.32	0.35	0.17	0.20	0.26	0.22
C_{41}	0.30	0.32	0.36	0.33	0.29	0.33	0.26	0.36	0.32	0.31	0.36	0.16	0.19	0.23	0.21
C_{42}	0.31	0.32	0.37	0.33	0.29	0.33	0.35	0.27	0.31	0.31	0.36	0.16	0.19	0.23	0.20
C_{43}	0.29	0.31	0.34	0.32	0.27	0.31	0.29	0.32	0.23	0.29	0.33	0.15	0.18	0.20	0.17
C_{44}	0.29	0.30	0.34	0.32	0.27	0.31	0.31	0.32	0.30	0.23	0.32	0.15	0.18	0.20	0.17
C_{45}	0.29	0.30	0.34	0.32	0.27	0.31	0.31	0.32	0.30	0.30	0.25	0.15	0.18	0.20	0.17
C_{51}	0.12	0.12	0.14	0.13	0.11	0.12	0.12	0.13	0.12	0.12	0.13	0.05	0.09	0.09	0.08
C_{52}	0.14	0.15	0.19	0.18	0.15	0.17	0.15	0.15	0.14	0.14	0.15	0.09	0.08	0.12	0.10
C_{53}	0.17	0.18	0.25	0.23	0.18	0.21	0.21	0.21	0.18	0.17	0.21	0.11	0.13	0.12	0.12
C_{54}	0.14	0.14	0.16	0.15	0.15	0.17	0.14	0.15	0.14	0.14	0.17	0.09	0.10	0.11	0.07

TABLE IV: DIMENSIONS / CRITERIA ANALYSIS RESULTS

Dimensions / Criteria	x	y	x+y	x-y
Equipment (D_1)	**1.51**	**1.30**	**2.81**	**0.21**
Complete equipment (C_{11})	0.59	0.58	1.17	0.02
Proper equipment (C_{12})	0.58	0.60	1.17	-0.02
Command and control (D_2)	**1.04**	**1.49**	**2.53**	**-0.45**
Commander (C_{21})	0.47	0.48	0.95	0.00
Officer (C_{22})	0.46	0.45	0.91	0.00
Water supply (D_3)	**1.54**	**1.23**	**2.78**	**0.31**
Natural water access (C_{31})	0.56	0.52	1.09	0.04
Hydrants access (C_{32})	0.57	0.61	1.18	-0.04
Personnel training (D_4)	**1.43**	**1.36**	**2.79**	**0.07**
Knowledge (C_{41})	1.61	1.52	3.14	0.09
Rescue skills (C_{42})	1.60	1.59	3.19	0.01
Physical condition (C_{43})	1.46	1.46	2.92	0.00
Quantity (C_{44})	1.48	1.44	2.92	0.04
Safety (C_{45})	1.48	1.62	3.11	-0.14
Information services (D_5)	**0.73**	**0.87**	**1.60**	**-0.14**
Reporting process (C_{51})	0.32	0.33	0.65	-0.02
Dispatch process (C_{52})	0.39	0.40	0.79	-0.01
Data record (C_{53})	0.47	0.44	0.91	0.04
Feedback (C_{54})	0.37	0.39	0.76	-0.02

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