Dispatching Rescue and Support Teams to Events Using Ad Hoc Networks and Fuzzy Decision Making in Rescue Applications

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Abstract*-Rescue applications perform rescue operations such as medical emergencies, fire fighting, and earthquake responses. Ad hoc networks are composed of mobile wireless nodes which communicate to one another in order to transmit various messages to a desired centre. Integration of these networks and a knowledge-based system (e.g., fuzzy logic) in rescue applications can improve rescue operations. This paper proposes three methods to dispatch rescue teams to events, select members of the proper team, and dispatch the support teams to event locations. Each of the methods uses an individual fuzzy controller, which works based on prior humanistic knowledge. All vehicles in urban environments are equipped with mobile wireless nodes that construct an ad hoc network. Appropriate decisions are determined based on various messages, which are transmitted from vehicles to a main centre (e.g., fire department). The first method, DMRTFL, selects an appropriate path from the centre to the event location to dispatch rescue teams based on path length, path traffic, passage probability through each path, and arrival time. The second method, SMRTFL, selects proper members for the rescue and support teams based on age, experience, event type, and success probability. The third method, DMSTFL, chooses a suitable centre for dispatching the support teams to an event location based on essential parameters including arrival time, event type, amount of equipment, number of forces, and success probability. Simulation results indicate that the proposed methods surpass existing traffic methods in terms of arrival time.

Keywords- Dispatching Method; Rescue Teams; Ad Hoc Networks; Fuzzy Decision Making; Rescue Applications

I. INTRODUCTION

Rescue operations are utilized in rescue applications such as fire fighting, medical emergencies, and police forces [1, 2]. Rescue teams are dispatched from a main centre (e.g., fire department) to event locations so that they arrive at the occurrence position in a short time. Dispatching the teams with low delay causes significantly decreases humanistic disasters and financial losses. Hence, the use of an appropriate dispatching method is essential to rescue applications. Dispatching methods require consideration of transportation parameters such as all possible paths, path lengths, traffic rate on any path, and arrival time through each path. Moreover, members of rescue teams must be selected based on their age and experience according to conditions surrounding event locations in order to increase the success probability and decrease the impact of disasters.

In recent years, some applications such as target localization and tracking over a large geographical area, are achieved by WSN [3, 4]. CenWits (Connection-less Sensor-Based Tracking System Using Witnesses) [5] is a sparse sensor network for the search and rescue of subjects (e.g., people or wild animals). It is applied in emergency conditions in desert areas [6], such as the illustrated trail in Fig. 1. This framework is used to search and rescue lost hikers. One of the important safety-related activities of such technology is fire rescue. Finder [7], Geographic Information System (GIS) [8], and GEOMAC [9] represent some of the existing fire rescue systems. FINDER applies certain technologies to guide fire-fighters to locate wounded crew members. However, fire departments and incident commander cannot help the fire-fighters perform efficient operations, because they have no clear view of the fire field. Another general system in fire and rescue applications is GIS. In this system, users can view and analyze fire information graphically; GIS also maintains a database of fire field information.

A critical problem in large cities is traffic congestion. Signal control methods [10] and traffic management systems include traditional and intelligent control methods. Intelligent Transportation Systems (ITS) are used in developed countries to alleviate traffic congestion on roads and in urban areas [11]. Traffic management consists of the monitoring, control, and influence of traffic; it aims to enhance the effectiveness of existing infrastructure, ensure safe and trustful transport, address the environmental objectives, and ensure the fair allocation of spatial infrastructure (e.g., rail slots and road space) among competing users. The significant drawback of the existing traffic methods is that they do not use intelligent procedures which can determine appropriate paths from one position to another position. This creates a process that is not often accurate under complex and uncertain conditions. The use of a knowledge-based system (e.g., fuzzy logic [12]) with the aid of ad hoc networks [13] is proposed to solve existing problems.

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Fig. 1 Sampling map for trails outside Boulder, Colorado [6]

This paper proposes three methods for rescue applications based on fuzzy decision making with the aid of ad hoc networks. The first method selects an appropriate transportation path from a main centre (e.g., fire department) to an event location in order to dispatch rescue teams; it uses a fuzzy controller which works based on path length, path traffic, passage probability through each path, and arrival time. The second method choices appropriate members from among existing members at the centre for rescue and support teams; electing the appropriate members of the teams can increase success probability at the event. This method utilizes a fuzzy controller which works based on the age of team' members, prior experience of team' members, event type, and success probability. The third method selects a suitable centre for dispatching support teams to event locations. It applies a fuzzy controller which works based on arrival time, event type, amount of equipment, number of forces, and success probability. Note that vehicles in urban environments are equipped to utilize mobile wireless nodes to transmit their geographic coordinates to the main centre. Together, they construct an ad hoc network in order to report traffic conditions to the centre. Note that rescue teams are dispatched from main centre to the event location, and support teams can be dispatched from the main centre or other centres.

The rest of the paper is organized as follow. The related works about other dispatching methods are reviewed in section 2. In section 3, the fuzzy logic, components of the fuzzy system, and decision making are described. In section 4, three novel fuzzy methods are proposed to select the most suitable path from the related centre to the event location, select the proper members of rescue and support teams, and select the appropriate centre(s) for dispatching support teams. The proposed methods are analyzed by simulation in section 5. The conclusion of this paper is described in section 6.

II. RELATED WORKS

A road traffic management system for Dalian based on GIS and WebGIS is presented by Zhuo [14]. In this system, a digital road network database is constructed within GIS using a map of Dalian, and graphical database management programs are presented to maintain traffic information and realization of a Graphic User Interface (GUI). Furthermore, a shortest-path searching module is developed to excavate the network in the database. The core of this module is the Dijsktra shortest-path algorithm, which allows users to choose nodes and demonstrates the shortest-path in GIS map using the topological structure of the road network and the traffic characteristics of links.

Transport development must consider many constraints, such as the increase of traffic in the lack of urban infrastructure, expansion limitation due to available space and cost, the problem of the air pollution, and deregulation and concurrency of the states in the transport. The transportation system and road traffic management can be facilitated by Decision Support System (DSS). An instance of these systems is proposed by Ant system and regulation mode [15]. It considers two phases of the decision support system in a single architecture: selection of the shortest path between two points according to road users and regulation of the traffic to avoid jam according to road traffic management. In this system, the link between two points is weighted by traffic information. Thus, the generated graph is dynamic at any moment of time, and the shortest path between two points is chosen by the ant algorithm.

A hierarchical routing is developed by Tatomir and Rothkrantz, i.e., a hierarchy model splits the traffic networks into fewer complex and smaller networks [16]. The route operation is accomplished by utilizing an adapted version of the AntNet-algorithm. It is a decentralized routing algorithm that applies intelligent agents to determine the shortest routes. A two-dimensional road network is presented by Chopard et al. [17]. In this network, horizontal roads are composed of two lanes as eastward and westward motions. Furthermore, vertical roads consist of northbound and southbound lanes. Nikolova et al. have presented a method that the optimal path is selected by emphasizing the importance of the uncertainty consideration [18]. One of the main ideas on this system is that deterministic methods overlook the inherent occurrence of traffic and changing traffic conditions.

A method that a quantitative fuzzy-based model is presented by Wex et al. for the optimal allocation of distributed, heterogeneous rescue units, using fuzzy decision making to deal with non-statistical informational under uncertain conditions

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[19]. A Monte Carlo-based heuristic method is also presented, which offers decision support abilities to any commander. A fuzzy-based routing method is presented by Hanifi and Tofig for mobile ad hoc networks (MANETs) [20]. Each node is equipped with a GPS device to transmit its geographical coordinates to a centre. This method utilizes certain parameters (position of nodes, time interstice between two samplings, and the time interval between two pairs of samplings) which are determined based on the precision of the GPS tool and the motion coefficient of nodes.

An aggregated representation of traffic is provided by macroscopic models, and typically explained in terms of total flows per hour. Description of the travel time, speed, and higher moments of throughput are impossible in these models. These models are not applied in real-time traffic control and analysis. Additionally, artificial intelligent techniques are focused primarily on urban traffic, including the generic algorithm, neural network, and fuzzy control. Moreover, some models such as SPSA [21], the ant algorithm, timed Petri Nets [22], mobile agent [23], and the knowledge-based multi-agent system [24] have also been suggested.

III. A GLANCE ON FUZZY LOGIC

Fuzzy logic [12, 25, 26] is a major tool used to control and model uncertain systems. Furthermore, it is a useful tool for controlling and directing complex industrial processes, entertainment electronics, and expert systems. Fuzzy logic is generally a multi-valued logic. In this logic, the intermediate values can be considered between conventional evaluations such as yes/no, high/low, true/false, etc. However, the crisp sets are the classic mathematics sets. The elements of the crisp set that have been assigned the number 1 can be interpreted as the elements that are in the set, and the elements which have been assigned the number 0 are the elements that are not in the set.

Fuzzy logic presents a different concept for the development of models of physical processes. Fuzzy models do not include significant complexity. They are easy to understand, and very appropriate for nonlinear processes. Fuzzy controllers can be used in uncertain systems with incomplete information. Large and very complex controllers have already been developed for traffic control. They reduce the waiting time of the vehicles at traffic signals. In these algorithms, linguistic and inexact data are useful tools in the design of signal timings. The control algorithms using fuzzy logic result from linguistic control strategies that are decided by “if-then” statements.

Each element in the universe of discourse is a member of the fuzzy set to some, degree, perhaps even zero. The function that assigns a number to each element x of the universe is called the membership function $\mu(x)$. The fuzzy rules apply the input membership values as weighted operators to determine their effect on the fuzzy output sets of the ultimate output conclusion. The basic operations conducted on fuzzy sets are similar to operations conducted on crisp sets, including union, intersection, and negation. Zadeh [26] suggested the minimum operator for the intersection and the maximum operator for the union of two fuzzy sets. One fuzzy theory application is the use of fuzzy classifiers. Expert knowledge is applied and can be explained in a typical method using linguistic variables, which are expressed by fuzzy sets. A Fuzzy Logic System (FLS) is a system for nonlinear mapping of an input set to an output set. It consists of four sections: fuzzifier, fuzzy rules, inference, and defuzzifier. The fuzzifier unit converts a crisp value to a fuzzy value based on membership functions. The inference unit evaluates and combines fuzzy rules stored in the rule base in order to determine an appropriate decision. The defuzzifier unit converts a fuzzy value to a crisp value. The architecture of FLS is shown in Fig. 2.

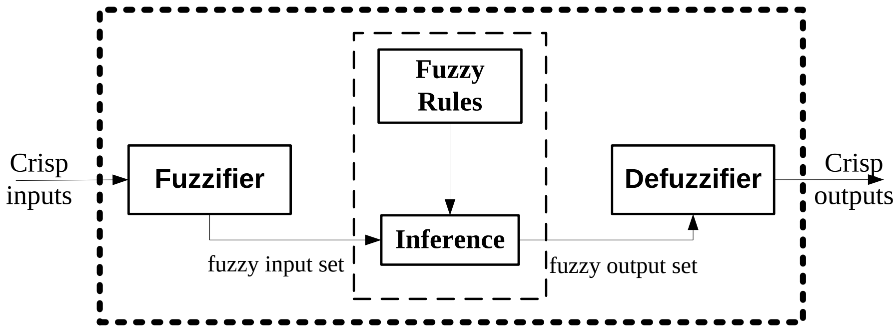

Fig. 2 The architecture of FLS

IV. THE PROPOSED METHODS USING FUZZY DECISION MAKING AND AD HOC NETWORKS

In rescue applications, rescue and support teams are dispatched from a main centre (e.g., fire department) to event locations through appropriate paths (e.g., the nearest path with low traffic), leading to a significant decrease in arrival times of the teams. Furthermore, humanistic members of the teams must be selected based on several important parameters (e.g., age and experience) in order to increase the success rate of the teams at event locations. To achieve these goals, three intelligent knowledge-based methods are proposed in this paper, based on fuzzy decision making with the aid of ad hoc networks. The first method, DMRTFL, selects an appropriate path from the main centre to the event location by a proposed fuzzy controller in order to dispatch rescue teams. It applies four essential factors including path length, path traffic, passage probability

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through paths, and arrival time. The path which has the shortest arrival time is selected as an appropriate path for dispatching the rescue teams. The second method, SMRTFL, chooses proper humanistic members from among existing members at centre(s) by a proposed fuzzy controller; it induces high success rates of rescue operations, and utilizes four essential factors including age, experience, event type, and success probability. The humanistic members which have the greatest success probability are chosen as proper members for dispatching missions. When extra forces are needed at an event location and the number of rescue teams is not adequate, support teams are dispatched to the event location in order to facilitate rescue operations. Therefore, it is possible that there exist several rescue centres in various areas; one of the centres is selected to dispatch support teams to the event location. The third method, DMSTFL, selects an appropriate centre to dispatch extra support teams to event locations according to another proposed fuzzy controller; it utilizes five factors including arrival time, event type, amount of equipment, number of forces, and success probability. The centre which has the greatest success probability is selected as the most suitable centre from which to dispatch support teams toward an event location. In all of the proposed fuzzy controllers, the fuzzification process is accomplished according to the triangular method [27], the inference process is performed according to the Mamdani fuzzy model [28], and the defuzzification process is achieved according to the center of gravity [29]. The mathematical equation of the triangular method is explained as follows:

$$\text{triangular}(x; l, c, u) = \begin{cases} 0 & x \le l \\ (x-l)/(c-l) & l < x \le c \\ (u-x)/(u-c) & c < x < u \\ 0 & x \ge u \end{cases} \tag{1}$$

where x describes each element of the universal set, l indicates the lower limit, u indicates the upper limit, and c determines the centre of the triangle as a<m<b. The mathematical equation representing the Mamdani model is represented as follows:

$$\mu_z(O) = \max[\min[\mu_x(I_1), \mu_y(I_2)]] \tag{2}$$

where I_1 and I_2 are the input sets, O is the output set, $\mu_x(I_1)$ is the membership function of x in set I_1, $\mu_y(I_2)$ is the membership function of y in set I_2, and $\mu_z(O)$ is the membership function of z in set O.The mathematical equation for the center of gravity is described as follows:

$$\text{Crisp}_{\text{value}} = \frac{\sum_{m=1}^{n} \mu_A(x_m) * x_m}{\sum_{m=1}^{n} \mu_A(x_m)} \tag{3}$$

where A is the output universal set of discourse, x_m is the element "m" of the fuzzy set A, $\mu_A(x_m)$ is the membership function of x_m, and n is the number of elements in fuzzy set A.

Suppose that all vehicles which move on roads and streets are equipped with a wireless node. All wireless nodes combine to construct an ad hoc network in order to transmit traffic conditions to the main centre. Each node determines its geographic coordinates with Global Positioning System (GPS) [30] technology. Afterward, each node reports its location to the main centre via GPRS [31] technology, Wi-Fi technology, or a local sink. When an event (e.g., a fire) occurs in an area, a user located at the main centre visually selects the event location from a desktop application. This is achieved in order to determine an appropriate path from the main centre to an event location by the proposed methods. A schematic of the network model considered by the proposed methods is shown in Fig. 3.

A. DMRTFL: Dispatching Method of Rescue Teams Using Fuzzy Logic

The first step in the proposed method to calculate the arrival time between adjacent intersections, and the next step is to select the appropriate path with minimum arrival time from the related centre to the event location. The rescue teams communicate with the related centres using equipped wireless nodes. Each vehicle of the rescue team is equipped with a wireless node. The route to the event location is determined before and after dispatching the teams. The most suitable path can be selected between the related centre and the event location before dispatching the teams. Moreover, the teams' current positions can be determined during movement, because conditions of paths may change after being dispatched. The rescue teams communicate with related centres using ad hoc networks during movement to the event location. Furthermore, the centres inform about the conditions of paths, such as traffic and passage probability, by receiving information from traffic control centres. Several paths may exist between the related centre and the event location. Each path is composed of several sub-paths. The proposed fuzzy method is applied to the sub-paths, and their arrival times are calculated. Furthermore, arrival times can be obtained from the sum of their sub-arrival times as follows:

$$\forall i \in n, \text{arrival time}(i) = \sum_{j=1}^{m} \text{arrival time}(j) \tag{4}$$

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where i = {1, 2, …, n}, n is the number of the paths, j = {1, 2, …, m}, and m is the number of the sub-paths in the related path. A schematic of the paths and sub-paths from the centre to the event location are shown in Fig. 4. The path with the shortest arrival time is selected as an appropriate path from the main centre to the event location in order to dispatch the rescue teams.

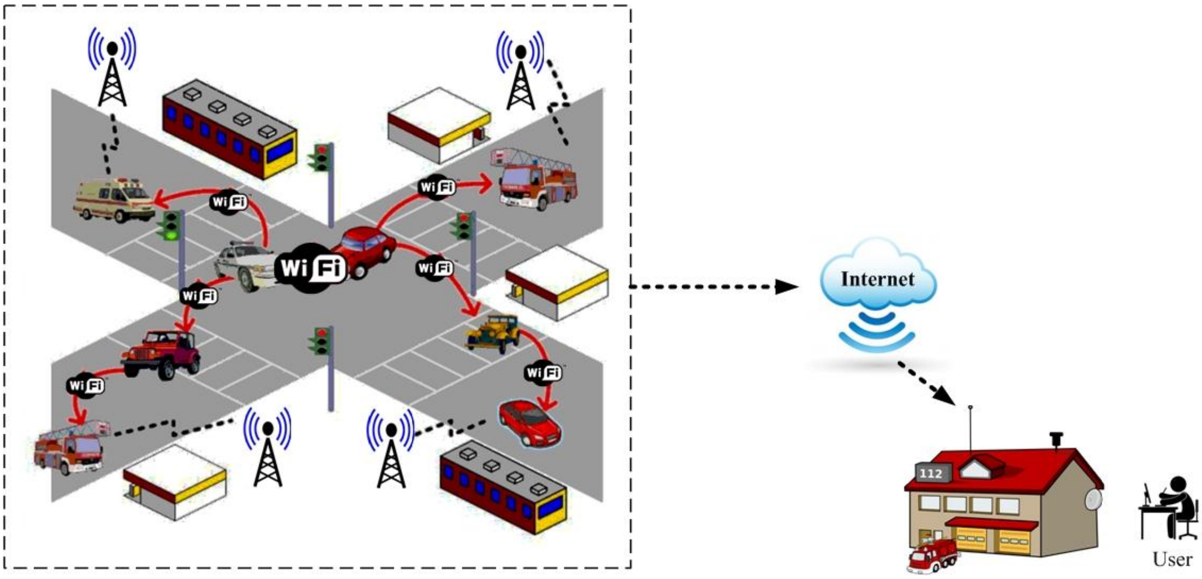

Fig. 3 A schematic of the network model

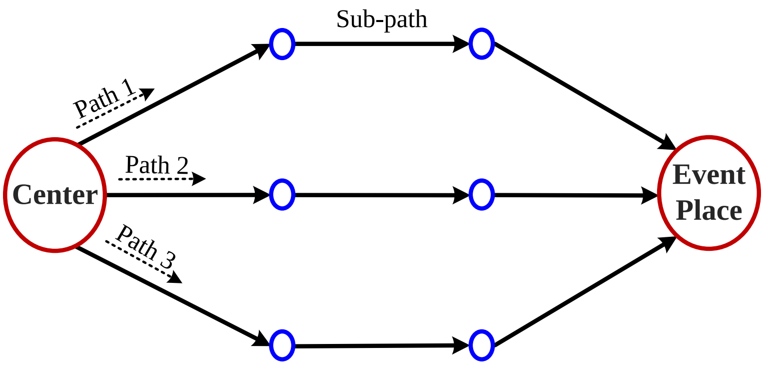

Fig. 4 Schematic of the paths and sub-paths from centre to event location

In the proposed fuzzy controller, “path length”, “path traffic”, and “passage probability” are input variables, and “arrival time” is the output variable. Details of the input variables are considered as follows: the length of the sub-path (denoted by PLi); the traffic level of the sub-path (denoted by PTi); and the passage probability (denoted by PPi). Here, “i” refers to the number of sub-paths in the existing path set. Passage probability is the probability of the events such as traffic jam, danger, and blockade on the paths. The output variable is the arrival time in the sub-path (expressed by ATi). PLi, PTi, PPi, and ATi take on the following linguistic values: VL (very short, very light, very low, soon); L (short, light, low, early); M (middle, normal, medium, ordinary); H (long, heavy, high, late); and VH (very long, very heavy, very high, too late). The fuzzy sets of input and output variables in DMRTFL are depicted in Fig. 5. Some fuzzy rules used in this work are shown in Table 1.

Rescue and support teams can be used in relief applications such as fire systems, medical emergencies, and police missions. The path of dispatching the rescue team to an event location can be selected by the proposed fuzzy method. Furthermore, selecting the suitable path of support teams to dispatch to an event location can be determined using a fuzzy procedure.

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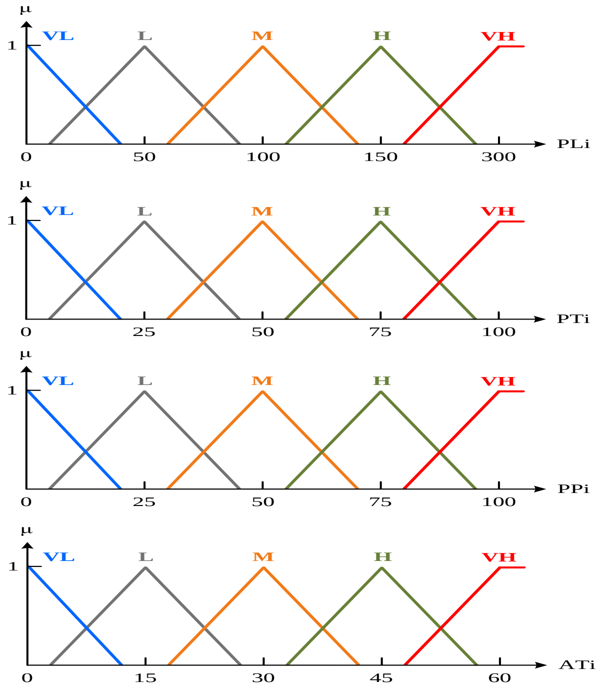

Fig. 5 Membership functions of input and output variables in DMRTFL

TABLE 1 SOME FUZZY RULES USED IN DMRTFL

No.	Input variable			Output variable
	Path length	**Path traffic**	**Passage probability**	**Arrival time**
1	middle	heavy	high	ordinary
2	very short	normal	low	soon
3	very long	light	medium	late
4	short	normal	medium	ordinary
5	long	heavy	very low	soon

B. SMRTFL: Selecting the Members of Rescue Teams Based on Fuzzy Logic

There are humanistic members at centre (s) of different locations to perform the required rescue operations. The members with the greatest success probability at event locations are chosen as proper members to dispatch as rescue and support teams to event locations. In the proposed fuzzy method, “age”, “experience”, and “event type” are input variables, and “success probability” is the output variable. Details of the input variables are assumed as follows: the age of member (denoted by AGj); the work experience (denoted by EXj); and the type of occurred event (denoted by ETj). Here, “j” refers to the number of existing members in the related centre. The unit of event type is varied in different events, e.g., it is initialized with the volume of fire in the fire systems. The output variable is the success probability of a member in the event location (expressed by SPj). Suppose for this work that AGj takes on the following linguistic values: Y (young), M (middle-aged), A (aged). EXj takes the following linguistic values: N (novice), L (little experience), M (moderate), EI (experienced), ET (expert). ETj and SPj take the following linguistic values: VL (very low), L (low), M (medium), H (high), VH (very high). The fuzzy sets of input and output variables in SMRTFL are depicted in Fig. 6. Some fuzzy rules used in this work are shown in Table 2.

Selecting the proper members of rescue and support teams is one of the essential requirements in rescue operations. In fact, members who have greater ability in relief operations should be dispatched to event locations. Some of the factors such as age, experience of members, and event type are effective parameters during the selecting procedure. The members of rescue and support teams can be selected by this method to increase the success probability of rescue operations. It is worth noting that the number of required members is determined by a related centre, according to event type. The members with greater success probability are selected by this method to dispatch to related event locations.

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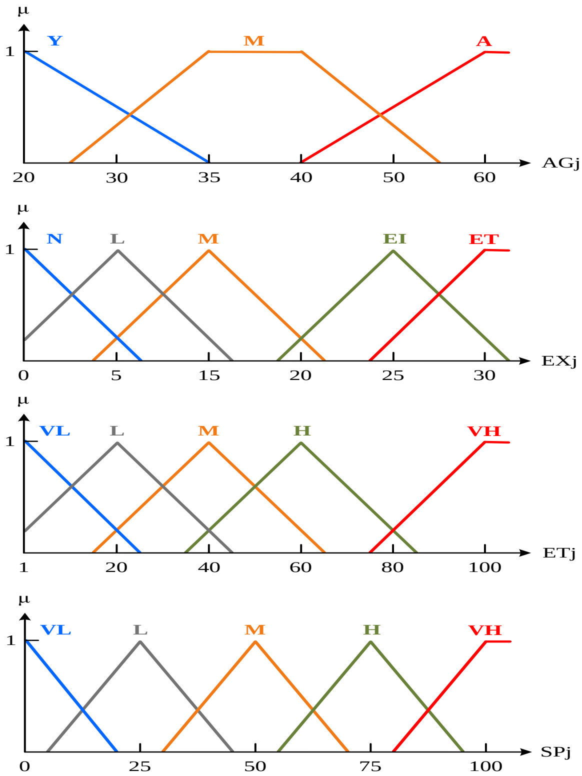

Fig.6 Membership functions of input and output variables in SMRTFL

TABLE 2 SOME FUZZY RULES USED IN SMRTFL

No.	Input variable			Output variable
	Age	**Experience**	**Event type**	**Success probability**
1	young	novice	very low	very high
2	young	little experience	low	high
3	middle-aged	moderate	very high	high
4	middle-aged	experienced	high	very high
5	aged	expert	medium	very high

C. DMSTFL: Dispatching Method of Support Teams Using Fuzzy Logic

When an extra number of teams are needed at an event location and the number of existing rescue teams is not adequate at that place, support teams are dispatched from other centre(s) to facilitate the rescue operations. It is possible that there exist several centres in different areas; therefore, it is possible that one of the centres is selected for the dispatching mission. The centre which has the greatest success probability is selected as the most suitable centre. In the proposed fuzzy method, “arrival time”, “event type”, “amount of equipment”, and “number of forces” are input variables, and “success probability” is the output variable. Detail of the input variables are considered as follows: the arrival time of an appropriate path from the related centre to an event location (denoted by ATk); type of occurred event (denoted by ETk); the amount of existing equipment in the related centre (denoted by NEk); and the number of existing forces in the related centre (denoted by NFk). Here, “k” refers to the number of existing centres for the dispatch of support teams. The unit of event type changes according to different events; e.g., it is determined according to the volume of occurred fire in fire applications. It is worth noting that the arrival time between related centres and event locations is calculated according to the procedure used in the DMRTFL method. The output variable is the success probability of a related centre for rescue operations in the event locations (expressed by SPk). Suppose for this work that ATk takes the following linguistic values into account: S (soon), E (early), O (ordinary), L (late), TL (too late). ETk takes the following linguistic values: S (slight), M (medium), E (effective), DR (drastic), DA (dangerous). NEk takes the following linguistic values: F (few), MO (moderate), MA (many), C (complete), A (advanced). NFk takes on the following linguistic values: FE (feeble), FW (few), MO (moderate), MA (many), L (lots). SPk takes the following linguistic values: VL (very low), L (low), M (medium), H (high), VH (very high). The fuzzy sets of input and output variables in DMSTFL are depicted in Fig. 7. The fuzzy rules used in this work are shown in Table 3.

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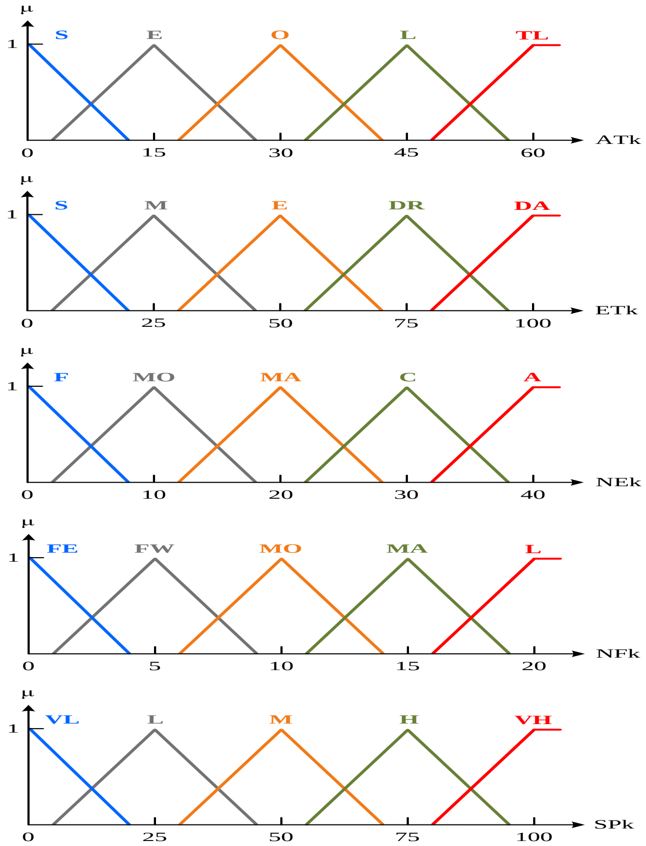

Fig. 7 Membership functions of input and output variables in DMSTFL

TABLE 3 FUZZY RULES USED IN DMSTFL

No.	Input variable				Output variable
	Arrival time	**Event type**	**Amountof equipment**	**Number of forces**	**Success probability**
1	O	S	A	L	VH
2	TL	S	A	FW	M
3	O	M	MO	MO	M
4	S	S	A	MO	VH
5	O	DR	MO	MO	H
6	S	S	A	L	VH
7	L	M	MO	MA	L
8	E	M	MO	MO	VH
9	L	E	F	L	L
10	E	S	A	MO	VH
11	TL	DA	F	MO	VL
12	E	S	F	MA	VH
13	L	M	MO	MO	L
14	TL	E	C	MA	L
15	S	S	F	L	VH
16	O	DA	A	FE	VL
17	L	S	F	L	M
18	S	M	MA	MA	VH
19	E	DA	F	MA	VL
20	TL	DA	C	MO	L

When an event occurs, it is possible that there are not sufficient equipments or forces in the local centre, or that the existing paths from the centre to the event location exhibit high traffic. Thus, the support teams are selected and dispatched from other centre(s) to event locations. The centre(s), which require less time to reach the event location and involve the sufficient equipment for rescue operations, are generally selected as candidate centre(s) for dispatching the required support teams to an event location. Therefore, a novel fuzzy method is proposed to calculate the success probability of centres in the rescue operations based on arrival time to event place, event type, amount of equipment, and number of forces in the related centre.

The suitable centre(s) for dispatching the support teams can be selected by this method to enhance the success probability of rescue operations. The number of required support teams is determined by the local centre based on event type so that all

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may be dispatched from one centre, or several different centres. The centre(s) which have greater success probabilities are selected by this method to dispatch the required number of support teams to related event locations. There is a main centre in the network so that selecting the suitable centre(s) for dispatching the support teams is performed by this centre. Thus, the main centre informs about the required conditions of other centres in order to apply the proposed procedure. When a centre is required to support teams, it sends the required number of teams to the main centre the; then, main centre selects the candidate centre(s) by the DMSTFL method, and reports the position of the event location and the number of support teams to selected centres.

V. PERFORMANCE EVALUATION

The proposed methods and other dispatching methods are simulated using MATLAB 7.10 simulator and the Routing toolbox. They are compared to the two existing traffic methods in terms of arrival time to an event location. The simulation process is accomplished during 30 minutes in a topographical area of dimensions 1000 m × 1000 m. The number of vehicles on the simulated area is 200, the vehicles move on roads and streets according to the random way point mobility model [32], and the maximum speed of the vehicles is 120 km/h. Note that each vehicle is equipped with a wireless mobile node to report traffic conditions to a main centre. The wireless nodes are randomly deployed so that that they transmit their data packets via wireless links or GPRS technology. Omni Antenna is selected as the antenna type of the nodes, and IEEE 802.11 is selected as the MAC version of the ad hoc network. The number of intersections is 15, the initial energy of wireless nodes is 100 J, the bandwidth of the wireless radio is 2 Mbps, and the transmission radius between adjacent nodes is 250 m. Moreover, the idle power of the nodes is 1W and the sleep power of them is 0.001W. The length of the data packets is 100 Bytes and Constant Bit Rate (CBR) is the traffic source for sending data. The nodes transmit a data packet to main centre, where each packet includes an identifier number (ID) of a sender node, geographic coordinates, and the sending time of the packet. Required energy of the nodes for transmitting and receiving the data packets are consumed according to the energy model presented by Bergamo et al. [33]. Simulation parameters are presented in Table 4. Performance evaluation of the methods is categorized into three groups: evaluation of DMRTFL, evaluation of SMRTFL, and evaluation of DMSTFL, explained as follows.

A. Evaluation of DMRTFL

The case study presented by Fig. 8 is considered for evaluation of the introduced fuzzy methods to dispatch rescue and support teams to event location; the location of points and paths between them are also considered. The nodes represent intersections between streets and roads, or special positions on streets and roads. Furthermore, all defined paths on the simulated environment are bi-directional. The appropriate path can be determined between two optional positions at any required time. According to the proposed method, the initial stage calculates the arrival time between adjacent intersections, and the subsequent stage selects the suitable path with the shortest arrival time from a related centre to an event location. Some simulation results calculating the arrival time between adjacent positions based on the proposed fuzzy method are shown in Table 5. Each entry explains the properties of any sub-path between two adjacent nodes in the case study. The “path length” and “path probability” are randomly determined in the deployment phase. The “path traffic” is calculated based on the number of vehicles presented on roads and streets, such as:

$$\mathrm{PT} = \left(1 - \frac{N_O}{N_I}\right) \times 100 \quad (5)$$

where N_I is the number of vehicles on a sub-path and N_O is the number of vehicles that have exited that sub-path. Note that “arrival time” is calculated by the first proposed fuzzy controller. The path which has the shortest arrival time is selected as an appropriate path from a centre to event location to dispatch rescue teams for rescue mission.

TABLE 4 SIMULATION PARAMETERS

Parameter	Default value
Simulation time	30 min
Topographical area (meters)	1000 m × 1000 m
Number of vehicles	200
Mobility model of vehicles	Random way point
Maximum speed of vehicles	120 km/h
Channel type	Wireless channel
Antenna type	Omni antenna
MAC type	IEEE 802.11
Number of intersections	15
Initial energy of nodes	100 J
Bandwidth of wireless radio	2 Mbps
Transmission range of nodes	250 m
Idle power	1 W
Sleep power	0.001 W
Data packet size	100 Bytes
Traffic source	CBR

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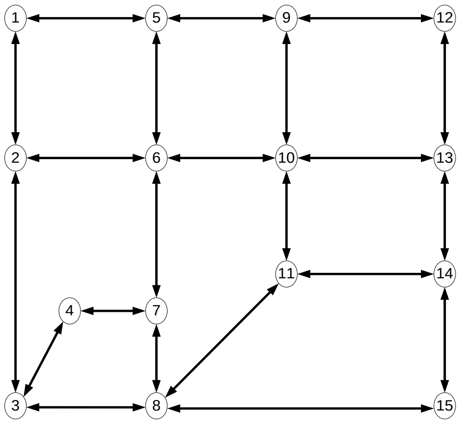

Fig. 8 Case study for evaluating proposed dispatching methods

TABLE 5 SOME SIMULATION RESULTS OF CALCULATING THE ARRIVAL TIME BETWEEN ADJACENT POSITIONS BY THE FIRST PROPOSED FUZZY CONTROLLER

Position		Input variable			Output variable
From	To	Path length (m)	Path traffic (%)	Passage probability (%)	Arrival time (min)
1	2	40	95	3	30
1	5	46	85	5	30
5	9	59	63	27	32.404
6	10	74	55	35	34.682
10	11	164	29	63	33.032
10	13	170	27	65	32.404
8	3	89	47	45	34.469
15	14	295	1	100	37.5
4	3	38	71	19	30
12	9	195	19	75	30

The proposed DMRTFL method is compared to methods in which the path length and path traffic are used to determine the best path. It is compared to ant-based traffic management [15] and GIS-based traffic management [14] in terms of the arrival time to the event location. It is assumed that ten events have happened in the network in different areas, as explained in Table 6. Note that the event time indicates the time of occurrence of the events. The source represents the position of the related centre (e.g., a fire department) and destination represents the position of the event location. Simulation results of evaluated dispatching methods based on the events considered by Table 6 are shown in Fig. 9. Note that "No." indicates the identifier number of the events. Analysis results demonstrate that the proposed fuzzy method surpasses both other dispatching methods in terms of arrival time. Note that the related centre is a main centre (e.g., a fire department) and that the event can occur at various positions.

TABLE 6 DETAILS OF TEN EVENTS FOR DISPATCHING RESCUE TEAMS

No.	Event time (min)	Position	
		Source	Destination
1	14	4	15
2	19	13	5
3	25	8	9
4	32	8	5
5	65	12	11
6	69	10	8
7	73	8	13
8	79	15	6
9	85	5	15
10	95	12	8

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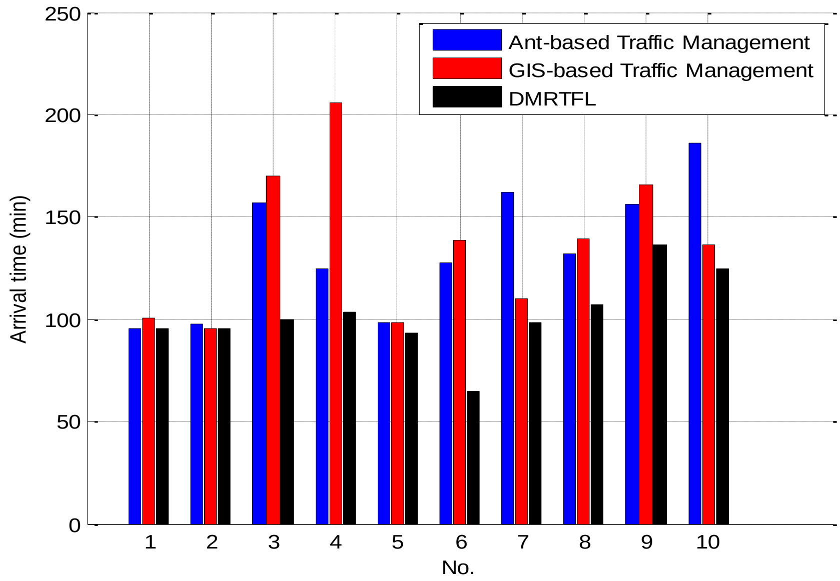

Fig. 9 Some simulation results of the evaluated methods for dispatching rescue teams

The simulation results indicate that sometimes the performance of the proposed fuzzy approach identical to results obtained by other methods; however, often the most optimal path is selected by the DMRTFL method, which reduces the dispatching time of the rescue team to an event location. The proposed fuzzy method can determine the suitable path under both normal and abnormal traffic conditions. Schematic routing from position 1(source) to position 15(event) is shown in Fig. 10.

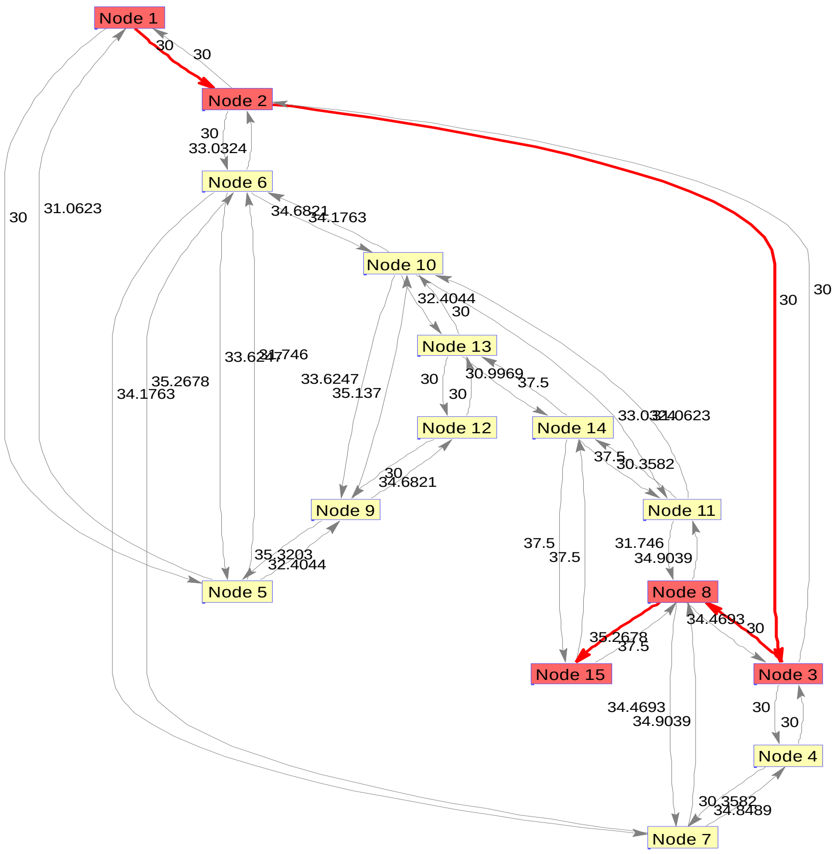

Fig. 10 Schematic routing from position 1(source) to position 15(event)

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B. Evaluation of SMRTFL

SMRTFL is proposed as a novel fuzzy method to select the proper members of the centres for dispatching rescue and support teams to event locations. There are many forces in the centres, so that they have different conditions and work experiences. Thus, the required number of members who demonstrate greater success probability, is selected by this method. It is assumed that there are ten members at a desired centre to dispatch to an event location. As presented in Table 7, the members have different ages and prior experiences, and the event type is different for each entry. The second proposed fuzzy controller determines a success probability for any member according to “age”, “experience”, and “event type” in order to select the proper members.

Some simulation results of selecting the members in an optional centre using SMRTFL are shown in Fig. 11. In the proposed fuzzy method, the success probability of existing members in the related centre is calculated, and the required number of members is selected according to their success probabilities. The priority of members in the considered work study is as follows: M9 > M5 > M7 > M10 > M6 > M2 > M3 > M8 > M4 > M1. If three members are required, then M9, M5, and M7 are selected and dispatched to the event location with rescue or support teams.

TABLE 7 CHARACTERISTICS OF SELECTING THE PROPER MEMBERS USING SMRTFL

Member ID	**Age**	**Experience**	**Event type**
1	30	8	60
2	40	15	45
3	50	25	25
4	45	18	8
5	35	13	85
6	22	3	15
7	46	28	55
8	27	10	74
9	33	20	96
10	51	15	35

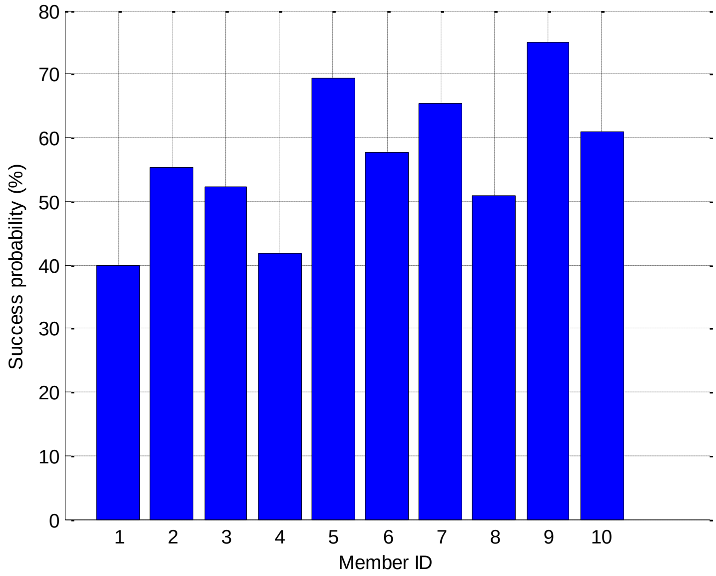

Fig. 11 Some simulation results of member selection using SMRTFL

C. Evaluation of DMSTFL

When an event occurs, it is possible that there may not be sufficient equipment or members in the local centre, or that the existing paths from the centre to the event location are experiencing heavy traffic. Therefore, one or several centres should be selected as candidate centres for dispatching the support teams to event locations. The candidate centres are selected based on arrival time to event place, type of occurred event, amount of existing equipment, and number of existing forces in the centres. DMSTFL calculates the success probability of centres for selecting the suitable response centre(s). The case study explained by Fig. 12 is assumed for evaluation of the proposed fuzzy method, with five centres to dispatch the support teams toward the

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event location, which is located at position 15. Support teams are dispatched from a centre or several centres with the highest success probabilities according to the required number of support teams.

As explained in Table 8, each centre includes various features such as arrival time, amount of equipment, and number of forces. Meanwhile, event type involves various values during simulation. The success probability of each centre is calculated by the third proposed fuzzy controller. Some simulation results of dispatching the support teams using DMSTFL are illustrated in Fig. 13. There are five centres in the case study considered by Fig. 12 for selection of the appropriate centre(s) so that every centre includes a variety of features and characteristics. Moreover, the number of the required support teams is determined by a local centre. The first stage is to calculate the success probability of the centres, and the second stage is selection of the required number of teams from existing centres based on their success probabilities and priorities. The priority of centres in the assumed work study is as follows: C5 > C3 > C2 > C1 > C4. If there are two support teams at every centre and four support teams are required, then C5 and C3 are selected to dispatch the support teams to the event location.

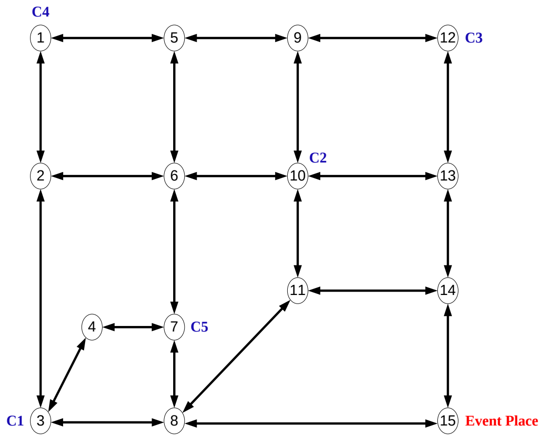

Fig. 12 Case study for evaluating the DMSTFL method

TABLE 8 FEATURES OF FIVE CENTRES FOR DISPATCHING SUPPORT TEAMS USING DMSTFL

Centre ID	Arrival time (min)	Event type	Amount of equipment	Number of forces
1	50	80	38	17
2	30	55	5	12
3	34	25	10	5
4	55	50	18	17
5	56	25	10	5

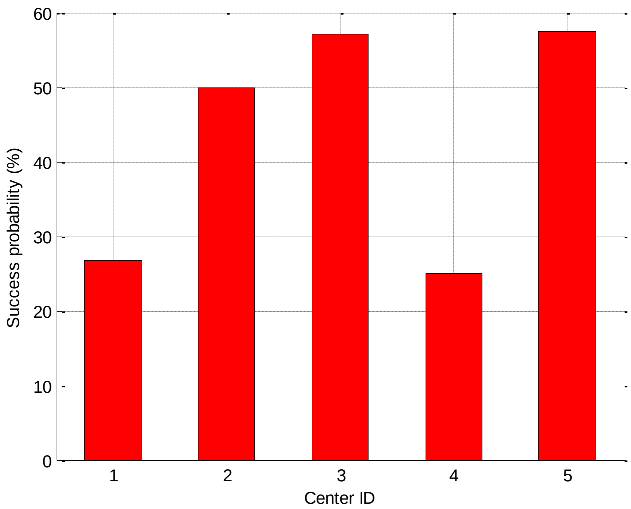

Fig. 13 Some simulation results of dispatching the support teams using DMSTFL

Finder System [7] uses technology to guide fire-fighters to find injured crew members. The incident commander and fire department have no clear view of the entire fire field, so that it does not help to make proper decision of firefighting operation. The work presented by Wex et al. uses a fuzzy-based model to determine rescue units performed by the incident commander

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[19]. Moreover, it does not take into account certain essential human characteristics such as age and experience, nor does it utilize the various types of events (e.g., the intensity of a fire event) which are required in order to select the appropriate rescue members. The work presented by Hanifi and Tofig uses a fuzzy-based method to determine a path between two positions with the aid of MANETs [20]. However, the utilized fuzzy parameters (position of nodes, the time interstice between two samplings, and the time interval between two pairs of samplings) are not sufficient and robust for a MANET or for a rescue mission. There are certain essential traffic factors (such as metric length of paths, traffic load of paths, and pass probability through paths) that must be considered by traffic routing methods and rescue applications. Moreover, it uses certain mathematical equations that are not required for fuzzy controllers. This method works slightly similar to our proposed DMRTFL method, but with the aid of certain weak parameters. Hence, most existing methods either use a routing method for ad hoc networks or use a fuzzy-based method. Moreover, they select an appropriate path from one position to another position based on weak and unusual parameters. In contrast, the proposed DMRTFL method includes three important features: (i) use of ad hoc networks for communication between rescue teams and rescue centre(s); (ii) determining appropriate decisions based on a fuzzy-based system; (iii) use of parameters which are required for traffic conditions. Additionally, the proposed SMRTFL method uses a fuzzy controller with the aid of some essential humanistic factors that are not considered by existing methods. Moreover, the proposed DMSTFL method not only selects an appropriate path from rescue centre(s) to an event location, but also selects an appropriate rescue centre for dispatching extra support teams to event locations. The rescue centre with the shortest arrival time toward an event location is selected for a support mission. All parameters and procedures utilized by the proposed methods have not been previously considered by previous research.

VI. CONCLUSIONS

Rescue operations are used in rescue applications such as fire systems, medical emergencies, and police forces. Rescue and support teams are dispatched from a main centre (e.g., fire department) to event locations via the path which has the shortest arrival time. Meanwhile, proper humanistic members of rescue teams must be chosen for rescue missions in order to increase the success probability. Fuzzy logic is a multi-valued model for uncertain systems with incomplete information. It is simple and easily understandable, and very applicable to nonlinear processes. Traffic control can be developed by large scale fuzzy controllers. Fuzzy decision making is a major tool to model and control expert systems. A set of wireless mobile nodes constructs an ad hoc network; traffic control and automobile tracking are some of the applications that can be investigated according to these networks. The use of fuzzy logic with the aid of ad hoc networks can increase the efficiency of rescue operations.

In this paper, three methods are proposed to select an appropriate path from a main centre to an event location, to choose proper human candidates for rescue missions, and to select the suitable centres to dispatch the support teams to the event location. Each method uses an individual fuzzy controller to achieve the above goals. The first method, DMRTFL, selects an appropriate path from the main centre to the event location for dispatching the rescue teams based on path length, path traffic, passage probability, and arrival time. The path which has the shortest arrival time is selected as an appropriate path for dispatching the rescue teams. The second method, SMRTFL, chooses appropriate members for rescue and support teams based on age, experience, event type, and success probability. The members with the greatest success probability are chosen as the appropriate members in order to dispatch on the rescue and support teams to event locations. When additional forces are needed at event locations or if the existing rescue teams are not sufficient, support teams are dispatched to the event location to facilitate the rescue operations. As there may be several centres at different positions, one centre is selected to dispatch the support teams to an event location. The third method, DMSTFL, chooses a suitable centre for dispatching the support teams to event locations according to arrival time, event type, amount of equipment, number of forces, and success probability of the centres. The centre which has the greatest success probability is selected as the suitable centre to dispatch support teams to the event location. Note that the rescue and support teams communicate with related centres during travel to the event location by wireless mobile nodes. The simulation results demonstrate that the proposed fuzzy method is a suitable method, because it considers several factors in order to select the best dispatch path and to choose the appropriate members for rescue and support. Comparison results demonstrate that rescue teams chosen according to the proposed methods arrive at event locations earlier than those chosen by other traffic methods. For further work, more traffic and human parameters (e.g., the number of vehicles present on paths and the height of rescue members) can be incorporated into the proposed fuzzy controllers for selecting the appropriate paths and the appropriate human members.

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