# Developing a Multi-agent Based Modeling for Smart Search and Rescue Operation

**Sanaz Azimi, Mahmoud Reza Delavar and Abbas Rajabifard**

**Abstract** One important issue aftermath of disasters is the optimum allocation of the medical assistance to the demanded locations. In this paper, the optimum allocation of the medical assistance to the injured according to a multi-criteria decision making is performed by Multiplicatively Weighted Network Voronoi Diagram (MWNVD). Particle Swarm Optimization (PSO) is applied to optimize the MWNVDs. In this paper, two types of multi-agent rescue models for incorporating the allocation of the medical supplies to the injured locations according to the generated PSO-MWNVDs, wayfinding of emergency vehicles as well as using smart city facilities were proposed. In one of the proposed model, the priority of the injured for receiving the medical assistance, information transfer about the condition of the injured to the hospitals prior to ambulance arrival and updating of ambulance route were considered. Another proposed model has facilities of coordination of emergency vehicles with traffic lights in the intersection and updating of fire engine route compared to the facilities of the first one. The partial difference between the estimated and expected population for receiving the medical assistance in MWNVDs is computed as 37%, while the PSO-MWNVD decreased the mentioned difference to 6%. Also, the time evaluation of the mentioned proposed models and another multi-agent rescue operation model, which uses MWNVD and does not have the studied smart facilities was performed. The results show that the response time of ambulances to the injured and the ambulance mission duration in the proposed model, that has more smart facilities, is improved to other models.

S. Azimi · M. R. Delavar (✉)
School of Surveying and Geospatial Engineering, College of Engineering,
Center of Excellence in Geomatic Engineering in Disaster Management,
University of Tehran, Tehran, Iran
e-mail: mdelavar@ut.ac.ir

S. Azimi
e-mail: sanazazimi@ut.ac.ir

A. Rajabifard
Department of Infrastructure Engineering, Centre for Spatial Data Infrastructures
and Land Administration, The University of Melbourne, Melbourne, VIC, Australia
e-mail: abbas.r@unimelb.edu.au



O. Altan et al. (eds.), *Intelligent Systems for Crisis Management*,
Lecture Notes in Geoinformation and Cartography,
https://doi.org/10.1007/978-3-030-05330-7_6

## 1 Introduction

Disasters can have highly destructive effects on society. The high density of the population, buildings, and infrastructure in cities cause them vulnerable to disasters (Zhuang and Bier 2007; Li et al. 2011). Tabas, Rudbar and Bam earthquakes are the worst and deadliest earthquake disasters in the last 100 years in Iran (Ibrion et al. 2015). During the 208 natural disasters from 1900–2015 in Iran, 156332 people have been died and a number of people injured (Ghomian and Yousefian 2017). Providing the quick assistance to the wounded is a significant factor for increasing their survival probability.

There is the main requirement to the better assignment of the available medical assistance to the disaster sites in order to increase the survival chance of victims and improve the performance of the relief operation (Bostick et al. 2008). Therefore, the optimum allocation of ambulances to the emergency victims as fast as possible is essential where optimum routing of the ambulances to the emergency victims' locations is important at the same time. The optimum allocation of the victims to the appropriate emergency centers would require consideration of traffic conditions for transferring of the medical assistance to the wounded locations. Reducing the travel time of the ambulances to the emergency victims is one way to decrease the emergency vehicle response time (Billhardt et al. 2014).

Medical resource assignment has not been much considered in disaster management (Fiedrich et al. 2000; Gong and Batta 2007). There has been few research that explicitly study patients allocation problems to their most appropriate hospitals for receiving the medical assistance. In most of the studies, allocation of the nearest available ambulances to the emergency victims' location is performed. Bandara et al. (2014) showed that dispatching the nearest vehicle has not been applied in an optimum manner.

In some studies, the priority of the victims has been analyzed with regard to the severity of their injuries in order to receive the first aid. (Andersson and Värbrand 2007) illustrated that the vehicle with the shortest travel time route is dispatched to the patient with the highest priority location. López et al. (2008) proposed a multi-agent system for ambulances allocation that is considered the priority of patients. Bandara et al. (2014) showed that considering the severity level of patients leads to an increase in the average survival probability of patients.

In some research, the response time for emergency medical services is analysed. Haghani et al. (2003) proposed an optimization model for developing the flexible dispatching of the medical services by considering the ambulances available in the real-time.

On the other hand, the Voronoi Diagram (VD) can be used to determine the service area for urban facilities. Karimi et al. (2009) investigated the Ordinary Voronoi Diagram and multiplicatively weighted Voronoi Diagram for determining the space allocation of the educational centers. Rezayan and Najian (2008) studied Adaptive Multiplicatively Weighted Voronoi Diagram to determine service areas of the primary schools. The population density, proximity and safety of access rules parameters are investigated in order to minimize the proportional difference of the estimated and expected level of service in their proposed model. After applying the linear programming and simulated annealing optimizations algorithms, it was concluded that the linear optimization generates better results.

After occurring of disasters due to the blockage of many streets, investigating the access of relief groups to the street network and navigating the relief group in the disaster site are crucial. Yue et al. (2012) proposed an efficient approach for allocating and transferring ambulance dynamically. The purpose of this approach was ambulance navigation to the demand site in order to maximize the level of services of the emergency medical services system. Talarico et al. (2015) studied ambulance routing problem in order to find ambulances routes to serve a large number of injured people at the same time. Also, the effect of the number of ambulances, hospitals, and the priority of slightly and seriously injured patient's parameters was considered in the proposed model.

Search and rescue operation is a good application for agent-based modelling. Because the agent-based modelling is a natural way to model the complexity of disaster relief and relief groups interactions during an emergency situation. According to Rusell and Norvig (2003), the agent perceives its environment through sensors and acts upon them through its effectors. Multi-Agent Systems (MAS) are composed of multiple agents interacting with each other and with objects in a single simulation environment, for complying a common goal (Roozemond 2001). In some studies, the issue of the multi-agent rescue operation is concerned. Chavoshi et al. (2008) proposed a novel agent-based model of wayfinding for rescue operation based on landmarks remained after the earthquake. Sang (2013) modelled the multi-criteria decision making and dynamic tasks allocation to simulate the rescue process in multi-agent environments. In the proposed multi agent-based rescue model, the volunteer helping a disabled person in an emergency situation was considered. Wang et al. (2014) proposed a multi-agent cooperative coverage control model for the resource assignment to provide a distributed convergent approach to the ambulance position. The Voronoi set for each ambulance was determined based on keeping track of its neighbours. As Hawe et al. (2015) have indicated the agent-based modelling of the best allocation of resources for a hypothetical two-site incidents in order to minimize transportation time of the injured to the appropriate hospital was performed. Wang and Zlatanova (2016) proposed a multi-agent system for navigation of the first responders to emergency situations due to moving obstacles such as fires, plumes, and floods. Hooshangi and Alesheikh (2018) investigated a dynamic agent-based simulation model for urban search and rescue operation after occurring of the earthquake by the employment of geospatial information system and multi agent systems. Also, the dynamic task allocation and interaction between agents in the search and rescue operation were studied. Bae et al. (2018) proposed an agent-based model for coordinating the interaction between the disaster responders in order to manage a large number of victims by considering the limitation of the resources and facilities around the disaster site.

Smart health and transportation facilities can expedite the rescue operation. In the smart city, the real-time routing of the vehicles by considering traffic flow information, street status and traffic incidents are performed that can assist decreasing the emergency vehicle response time (Li et al. 2013).

The ambulances during their tasks have strengthened their communication with the related hospitals. On the other hand, ambulances transfer information about the condition of the injured to the hospitals prior to their arrival in order to provide appropriate treatment which can improve the survival probability of the patients. Also, the ambulance can get patient's medical reports in real time (Alami-Kamouri et al. 2017).

There have been a number of studies on the rescue operations in the smart city. Alazawi et al. (2014) have developed responsive systems to deal with accidents at different scales focusing on the smart transportation systems. Information from various sources such as the network of sensors and social networks has been gathered and information aggregation and decision making have been done accordingly. Billhardt et al. (2014) proposed a dynamic coordination model for ambulances fleet that combines ambulances redeployment mechanism with the optimal assignment of ambulances to victim locations at each moment. Djahel et al. (2015a) proposed a mechanism to leverage the communication between vehicles and traffic light controllers to prevent traffic congestions and ensuring the notable reduction of commuters' travel times in most large cities worldwide. Hirokawa and Osaragi (2016) investigated the accessibility of firefighters to the location of fire immediately after an earthquake by A* algorithm. When volunteers gathered information on street blockage, the arrival time of the firefighters to the location of fire have been reduced. Alami-Kamouri et al. (2017) presented a mobile agent-based model in order to transfer the information on patient conditions from smart ambulance to a hospital and getting a patient's medical report from the hospital to the smart ambulance in real time. Azimi et al. (2017) proposed a multi-agent model for aggregating the optimal allocation of service area to emergency centers based on population density, supply, demand and distance in the street network by applying the simulated annealing optimization algorithm to the constrained network Voronoi diagrams, ambulance routing under the travel distance and time and use of smart city facilities to improve rescue operations.

In this paper, we are faced with the situation how to expedite the allocation of medical assistance to the emergency victims after some disasters or accidents, based on the facilities of smart city and modeling of the multi-agent system.

The hypothesis of this paper is that optimum allocation of the medical services to the emergency victims' locations according to the priority of emergency victims, optimum wayfinding of ambulances by considering the blockage of streets and the smart city facilities can accelerate the rescue operation.

In this paper, the coordination among the agents in the model for ambulance fleets that provide the allocation of ambulances to the injured locations based on particle swarm optimization-Multiplicatively Weighted Network Voronoi Diagram (PSO-MWNVD) is proposed. In the proposed multi agent-based model, the urban street network, population density, and the ambulances of the emergency centers, optimum wayfinding of emergency vehicles to the injured location by considering travel distance, travel time, the street blockage and smart city facilities to improve the rescue operation are considered. The coordination center, emergency centers, ambulances, fire stations, fire engines and the wounded are modelled as agents.

In the proposed model it is assumed that the wounded delivered their locations by mobile global positioning system (GPS) and their initial symptoms to the coordination center agent.

The allocated Voronoi Diagram is determined for each emergency center. The number of ambulances are considered as the weight of the emergency centers. The Bi-label Dijkstra algorithm is used for wayfinding of ambulances in order to minimize travel length and travel time of the ambulances in the street network. Three types of multi-agent rescue operation models are implemented and their results are compared.

In the first type of the multi-agent rescue operation, the MWNVD is determined for each emergency center. The ambulances from proper emergency center based on the MWNVD that include the location of the wounded, according to the priority of the wounded and the ambulance numbers which are dispatched from the emergency center to the wounded sites are considered. This process is performed simultaneously for all the injured in different Voronoi diagrams. In the case that the ambulance capacity of each emergency center became zero, the response time to the new demand is delayed until the return of the first ambulance to the emergency center. In the case of the reported blocked street, the fire engine dispatched to the reported location.

In the second type of the multi-agent rescue operation, the PSO-MWNVD and the optimum weight for each of the emergency centers are computed. The ambulance from proper emergency center based on PSO-MWNVD according to the severity level of the wounded and the optimum ambulance numbers of the emergency center is transferred to the wounded site. The ambulances routes are updated according to blocked streets, if it is possible. Also, the ambulances are able to transfer information about the condition of the injured to the hospitals prior to their arrival in order to provide appropriate treatment. In case that all the ambulances of each emergency center are already dispatched, PSO-MWNVD for other emergency centers are activated and the rescue process is continued.

The third type of the multi-agent rescue operation model is similar to the second one with the difference that has more smart facilities. In the case of the reported blocked street, the proper fire engine dispatched to the reported location and the initial path of the fire engine is updated by considering the blocked streets. At each intersection, the traffic light phase becomes green during the passage of the emergency vehicles. After the passage of the emergency vehicles, the traffic light phase becomes red.

Finally, these three types of multi-agent rescue operation models are compared according to the optimum generated Voronoi diagrams, the arrival time of ambulances to the patient location and the length of time of ambulance's mission.

The outline of the rest of the paper is as follows. Section 2 provides the fundamental concepts for the proposed multi agent-based model. Section 3 explains the methodology of the allocation of the wounded to the emergency centers, the wayfinding of the ambulances in the disaster situation and the facilities of the smart city for accelerating the rescue operation in three types of the multi-agent rescue operation models. Section 4 explains the implementation and results of the proposed multi-agent rescue operation models. The results of the proposed models are discussed in Sect. 5. Finally, Sect. 6 presents conclusions and directions for future research.

## 2 Fundamental Concepts

### *2.1 Voronoi Diagram*

The Voronoi Diagram (VD) represents the partitioning of the given space into the regions based on a set of generators such that for each generator a corresponding region is determined (Okabe et al. 1992). In our application, the two-dimensional VD is considered. Network Voronoi Diagram (NVD) is the street network based VD that is utilized for allocating service areas to each emergency centers (Okabe et al. 1992; Aurenhammer and Klein 2000). The NVD partitions the nodes and the arcs of the network. In principle there are three types of NVDs including the Node Network Voronoi Diagram, the Arc Network Voronoi Diagram and the Area Network Voronoi Diagram (Okabe et al. 1992).

The Bi-Label Dijkstra shortest path algorithm is used for the construction of the NVD.

#### 2.1.1 Multiplicatively Weighted Network Voronoi Diagram

In Weighted Network Voronoi Diagram (WNVD), a weight is considered for all points. The weight of each generator is dissimilar in a Multiplicatively Weighted Network Voronoi Diagram (MWNVD).

By MWNVD, the demand nodes are assigned to the nearest emergency center which may cause an overloaded or underloaded problem in many VDs. The iteration process is applied to the MWNVDs in order to reduce the difference between the expected population in each MWNVD for using the services and the estimated population in the same MWNVD.

### 2.1.2 Particle Swarm Optimization—Multiplicatively Weighted Network Voronoi Diagram

Particle Swarm Optimization algorithms (PSO) (Yang 2010; Santosa 2006) is a metaheuristic and stochastic optimization algorithm that searches an objective spaces for attaining the best solution. Two major components of the movement of a swarming particle are a stochastic component and a deterministic component. Each particle is attracted toward the best position of their neighbourhood called global best $(gBest)$ and its own best location called local best $(lBest)$ in history. The position of particles is affected by velocity of the particles (Bai 2010; Engelbrecht 2006; Santosa 2006). The velocity and position of the particles are computing using Eqs. 1 and 2, respectively (Santosa 2006; Engelbrecht 2006). The $v_i(t+1)$ is the velocity of the particle $i$ in the time step $t$+1, $x_i(t+1)$ denotes the position of particle $i$ in time step $t$+1 and $t$ is discrete time steps.

$$v_i(t+1) = av_i(t) + c_1r_1[lBest(t) - x_i(t)] + c_2r_2[gBest(t) - x_i(t)] \tag{1}$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{2}$$

$a$ promotes local exploitation. $c_1$ and $c_2$ coefficients are learning rates for individual influence (cognitive component) and social influence (social component) that usually considered as 2. $r_1$ and $r_2$ are the random vectors in the range [0,1].

The procedure of PSO can be summarized as the following steps. At first, the size of the group of particles ($M$), the coefficients of $c_1$, $c_2$ and $a$ are specified. Then a random swarm is generated. After selecting the objective function, the value of the objective function is computed for each particle. The initial velocity of all the particles are assumed to be zero. All of the particles move towards the optimum point with a velocity. In each iteration, the $lBest$ for each particle with the lowest value of an objective function in the minimization case, $gBest$, the velocity and position of each particle are calculated.

Also, the aim of this optimization is to find the $gBest$ among all the current local best solutions after a certain number of iterations $(N_{\max})$ or until the objective improves. This process is repeated until the termination criteria is met (Rini et al. 2011).

In Particle Swarm Optimization-Multiplicatively Weighted Network Voronoi Diagram (PSO-MWNVD), the PSO algorithm is applied to MWNVD to determine optimum service areas for each emergency center.

In this paper, the number of ambulances of each emergency center is regarded as an emergency center weight. In the PSO-MWNVD algorithm, the initial position of each particle within the search space is determined by the initial weight of the emergency centers. The weight of the emergency centers is updated for each particle per iteration using Eq. 2. The process of the PSO-MWNVD continues until the difference between the demand and supply in the MWNVDs become minimum.

In the PSO-MWNVD algorithm, the mean proportional absolute error (*Er*) is regarded as the termination criteria to determine optimum service area for each emergency center. The error metric, *Er*, can be used for assessing partitioning method which is presented in Eq. 3 (Reitsma et al. 2007; Wood 1974).

$$Er = \frac{1}{N}\sum_{i=1}^{N}\frac{P_j - p_{i,j}}{P_j} \tag{3}$$

where $p_{i,j}$ is the estimated population of the service areas of emergency center $j$ in iteration $i$ as proportion of the total population. $p_{i,j}$ is get from the sum of the population in service areas of emergency center $j$. $P_j$ is the expected population for receiving the medical assistance in service areas of emergency center $j$ as proportion of the total population. $N$ is the total number of emergency centers, respectively.

The performance of Bi-Label Dijkstra shortest path algorithm for wayfinding the ambulances to the wounded location is explained in the next section.

## 2.2 Bi-Label Dijkstra Algorithm

In this paper, the Bi-label Dijkstra shortest path algorithm is used for the construction of the MWNVD. Each node in the network is assigned to singular emergency center by calculating the Bi-label Dijkstra shortest path algorithm based on the minimum travel time and the travel length from the emergency center to the node in the street network.

The bi-objective shortest path problem is a development of the classical shortest path problem that is related to the class of multi-objective optimization problems. In the specific network, the Bi-objective Shortest Path Problem uses for specifying the set of non-dominated paths between nodes by optimizing the two objective functions (Ticha et al. 2017; Serafini 1987).

In the Bi-label Dijkstra algorithm, each label represents a sub path from a source node $v_0$ to a certain node $u$ that is represented as $L = (u, d(L), t(L))$ where $u$ is the ending node of the sub path $L$. In addition, $d(L)$ and $t(L)$ represent the total distance and the total travel time associated with the sub path, respectively.

In this paper, lexicographic order is used for comparing the labels to determine the optimum path. A vector $a = (a_1, a_2)$ is lexicographically smaller than a vector $b = (b_1, b_2)$, denoted by $a < b$ if either $a_1 < b_1$ or both $a_1 = b_1$ and $a_2 < b_2$. A path $p_1$ lexicographically smaller than path $p_2$ if and only if $(t(p_1), d(p_1)) <_{lex} (t(p_2), d(p_2))$. $d(p)$ and $t(p)$ represent the total distance and the total travel time associated with the path $p$, respectively (Pyrga et al. 2008).

## 2.3 Smart Transportation and Smart Health

In the smart city (Li et al. 2013; Bakıcı et al. 2013), better and safer living conditions for citizens, including lack of restrictions on transportation and medical care, city administration, crisis management and so on are established.

In a smart city, the real-time routing of vehicles according to traffic density information, street condition, temperature and traffic accidents are recorded by sensors (Li et al. 2013).

Intelligent transportation systems (ITS) are a symbol of smart cities. ITS centers collect and reserve real-time road traffic data from various sources to reduce traffic congestion problems (Imawan et al. 2016).

In the emergency situation, accomplishing of actions at dispatch time of the emergency vehicles for ensuring the quick possible response to an emergency is essential. Two of the emergency actions are discussed below.

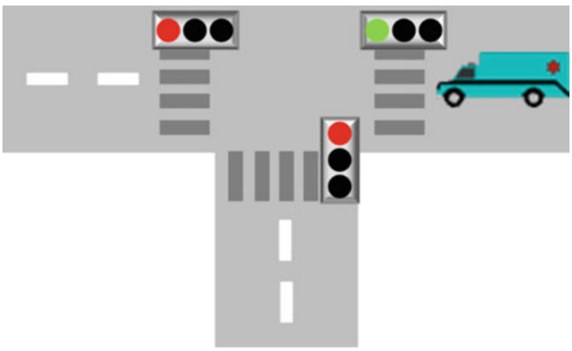
The effective coordination between the emergency vehicle and the traffic light controller at each intersection is the first one. When the emergency vehicle reaches a new road segment, the current traffic light phase can be changed or its duration extended to ensure that the emergency vehicle meets green light only (Djahel et al. 2015a, b). After the passage of the emergency vehicle, the traffic light becomes red for preventing the passage of others vehicles. So, the traffic congestion at the next intersection for passage of the emergency vehicle reduced (Fig. 1).

The second action is the rerouting of the emergency vehicles in faced with some blocked streets and traffic congestion situation toward emergency situations (Djahel et al. 2015b).

To make closer a city to the smart city, improving the different areas that are part of the city such as the health sector is necessary (Alami-Kamouri et al. 2017).

In disaster response situation, if information about condition of the wounded persons are announced to hospitals prior to their arrival, the hospitals can prepare pre-arrival support to the wounded persons. So, the relevant actions about the appropriate treatment or operation can be performed in the hospitals. Also, the ambulance team can get additional information about special patients from the

**Fig. 1** Coordination of emergency vehicles with lights for crossing the intersection



hospitals and perform proper actions. So, the ambulance team and the hospital team can more adequately response, quickly provide services to the wounded and avoid delay in commencing patient treatment (Alami-Kamouri et al. 2017; Mustafa 2013).

## 3 Methodology

After the occurrence of a natural disaster, the locations and initial symptoms of the wounded are delivered to the coordination center. The priority of the wounded according to their severity level is specified. The wounded with severe injuries more quickly receive the medical assistance. The service areas of emergency centers for delivering medical assistance to the wounded according to the population, supply, and the street network are determined by MWNVD and PSO-MWNVD. The number of ambulances in each emergency center is considered as an emergency center weight. The Bi-label Dijkstra algorithm is applied for wayfinding of ambulances in order to minimize the ambulances travel time and the route length in the street network.

In this study, the three types of the rescue operation models are considered. Agent-based simulation (ABS) is able to provide a natural description of the rescue operation situations. The multi agent-based rescue operation for modeling the allocation of ambulances to the injured location, reallocation of ambulances and the facilities of the smart city in order to improve the relief operation for these three types of the rescue operation models is performed.

As shown in Fig. 2, the coordination center, the emergency centers, ambulances, fire stations, fire engines and the wounded are modeled as agents in Anylogic simulation software with specific attributes and behaviours.

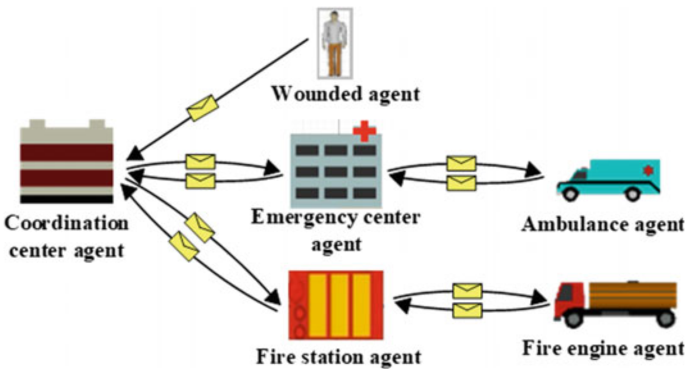



**Fig. 2** The communication of agents in the proposed models (Azimi et al. 2018)

The emergency management is usually controlled by an emergency operation center. In this study, the «coordination center agent» implement the role of the emergency operation center.

The task of this agent is determination and assignment of tasks to other agents of the proposed models. The coordination center agent communicates with other agents and updates its database. The wounded agent delivers help demand to the coordination center agent. The coordination center agent determines the appropriate emergency center and assigns the task of providing medical assistance for the injured based on the information received from the injured person and according to the VDs. The coordination center agent will share reports on road blockage and the location of the wounded with other agents for considering these reports during their navigation. The coordination center agent will determine the appropriate firefighting organization according to the location of the blocked streets, the location of firefighting organizations, the number of available fire engines, and the distance as well as time of accessing the fire engines to the blocked street. Then, this agent will send the blocked street information to the determined firefighting organization.

The emergency center agent receives the information and status of the injured, updates its information and dispatches an ambulance without a mission to the injured location.

The ambulance agent receives the injured person information from the emergency center agent, is delivered to the wounded location and communicates with the emergency center agent during its mission. When the ambulance reaches a new intersection, the traffic light phase becomes green and after its passage becomes red. Also, the ambulance agent will report the coordination center agent when faced with the new blocked street that is faced and update its route accordingly. Figure 3a explains the ambulance agent responsibilities and performance from the emergency center to the injured location.

The fire station agent receives the location of the blocked street from the coordination center agent and updates its database based on new information. This agent dispatches a fire engine agent to the reported blocked street. The fire station agent continuously communicates with the fire engine agent during its mission. This agent delivers the fire engine reports about the new blocked street and the location of the new wounded to the coordination center agent. The fire station agent after the completion of the fire engine mission, will inform the coordination center agent about its preparation for accepting the new mission.

The fire engine agent actions from the fire station to the blocked street are shown in Fig. 3b. The fire engine agent, after receiving the message from the fire station agent, will dispatch to the reported blocked location. The fire engine agent is responsible for shutting down the fire and removing the related obstacles. During its mission, the initial path of the fire engine is updated in order to minimize travel time and distance. During the mission, the fire engine agent is communicated with the fire station agent and reports the performance of its mission and its preparedness for initiating a new mission. These agents inform the fire station agent in the event of encountering the blocked streets or the injured. Traffic light phase becomes green in the event of passage of the fire engine and after that becomes red.

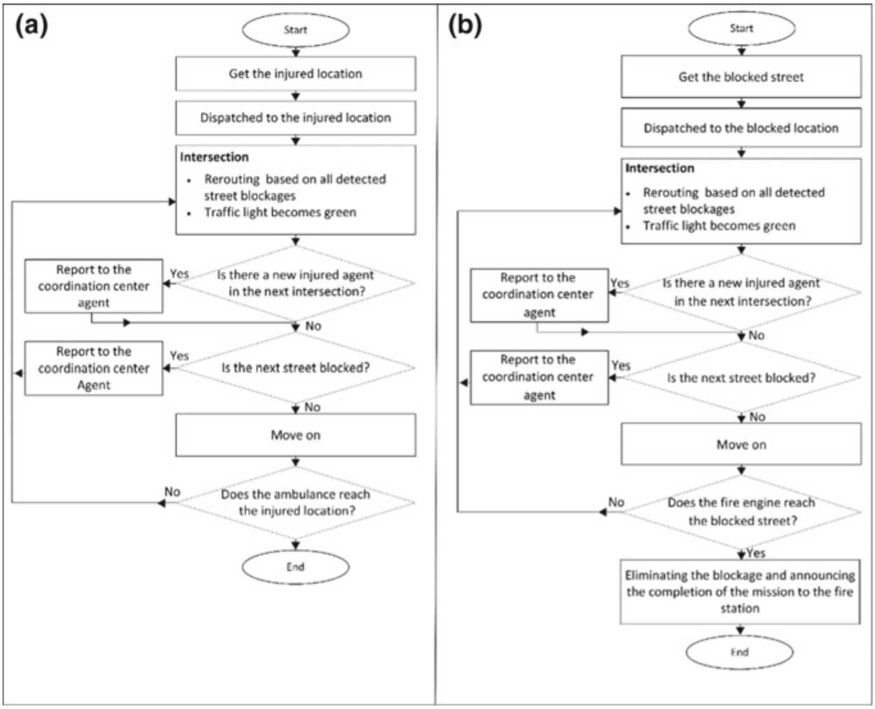



**Fig. 3** **a** The ambulance agent performance from the emergency center to the injured location, **b** The fire engine agent performance to complete one mission

The three types of the rescue operation models were implemented in the multi agent-based simulation environment.

In the first type of the rescue operation model, after determining the MWNVD for each emergency center, the proper emergency center according to the generated MWNVDs is allocated to the demand location. The emergency center due to the priority of the demand is delivered the ambulance to the demand location. The ambulance route is determined according to the goals of minimizing the route length and travel time at the beginning of its movement which is unable to update when faced with the blocked street. So, the ambulance will be delayed until the fire engine resolved the blockage of the street. The initial ambulance number of the emergency center is considered in the computation. In the case that ambulance capacity of each emergency center is fully employed, a new demand will not be delivered to the related emergency center until at least one of the ambulances of this emergency center completes its mission and returns to the emergency center. In this case, the wounded demand for receiving the first aid will be answered late and the injured survival probability reduced.

In the second type of the rescue operation model, the PSO iterative mechanism decreases the difference between the supply (the expected population lives in the region for using the services) and the demand (the estimated population lives in the region) in the MWNVD. So, the optimum PSO-MWNVD and optimum ambulance number for each emergency center are determined. The ambulance from proper emergency center that is located in PSO-MWNVD including the location of the wounded, according to the severity level of the wounded and the existing ambulances of the emergency center is dispatched to the wounded location. During the mission, the ambulance can benefit from the smart city facilities that are explained below. The optimum ambulance route is specified in order to minimize the route length and the travel time at the beginning of its movement. If the ambulance is faced with some blocked streets, the optimum route from the current location to the destination is re-calculated. The ambulance on the way back from the injured location to the emergency center, is able to send the name and the current state (such as heart rate, body temperature, blood pressure and blood type) of the injured to the hospital. Figure 4 shows[1] the list of some relevant information about the condition of the patients en route to the hospital[2]. Figure 5 shows the two-way communication between the hospital and the ambulance. In the case that the ambulances of many emergency centers during the mission are fully employed, responding to the new demand is different form the first type of the multi-agent rescue operation model. In this case, PSO-MWNVD is re-calculated for the emergency centers that have free ambulances and the rescue operation process is continued.

The third type of the rescue operation model is similar to the second one with the difference that it has more smart facilities. When the emergency vehicle arrives at each intersection during its mission, the traffic light phase becomes green until the emergency vehicle passes. After the passage of the emergency vehicle, the traffic

| | | | |
|---|---|---|---|
| **Identification** | | | |
| Name: | Time: | Date: | Chief complaint: |
| SSN[1]: | Age: | Gender: | Phone number: |
| **Vital Signs** | | | |
| Pulse Rate: | Blood Type: | Right Pupil: | Blood Pressure: |
| Body Temprature: | Respiration: | Left Pupil: | SPO2[2]: |
| **Status** | | | |
| Perfusion: | Burns: | Skin Condition: | Wounds: |
| Mental State: | Bleeding: | Skin Color: | Fractures: |

**Fig. 4** List of information about condition of the wounded by the ambulance to the hospital (Azimi et al. 2018) (Social Security Number) (Blood Oxygen Saturation Level)

[1]Social Security Number

[2]Blood Oxygen Saturation Level

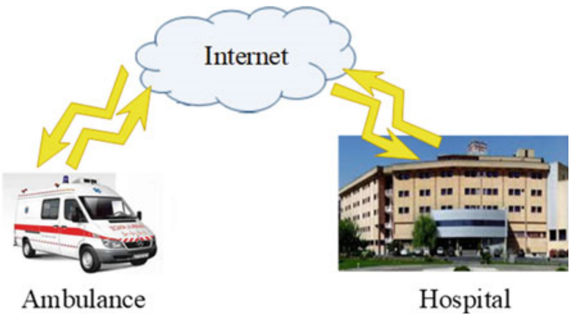



**Fig. 5** The two-way communication between the ambulance and the hospital (Azimi et al. 2018)

light phase becomes red. Therefore the traffic congestion at the next intersection for passage of the emergency vehicle will reduce and the chance of saving the lives of the injured increase. Also, after the detection of the new blocked street, the appropriate fire engine is dispatched to the reported location and the initial path of the fire engine is updated by considering the blocked streets.

## 4 Implementation

The proposed multi-agent rescue operation models are implemented in a part of Tehran municipal District 5. Figure 6 represents the study area that is limited to the Hakim highway from North, the Sanaye Havapeymayi Street and Sattari highway from West, the Lashkari highway from South and the Jenah highway from East.

The topographic map of National Cartographic Center (NCC) at the scale of 1:2000 was used in this study. The emergency center part of the Sarem Specialist hospital, Ebne Sina hospital, Fatemeh Zahra health center and Payambaran hospital

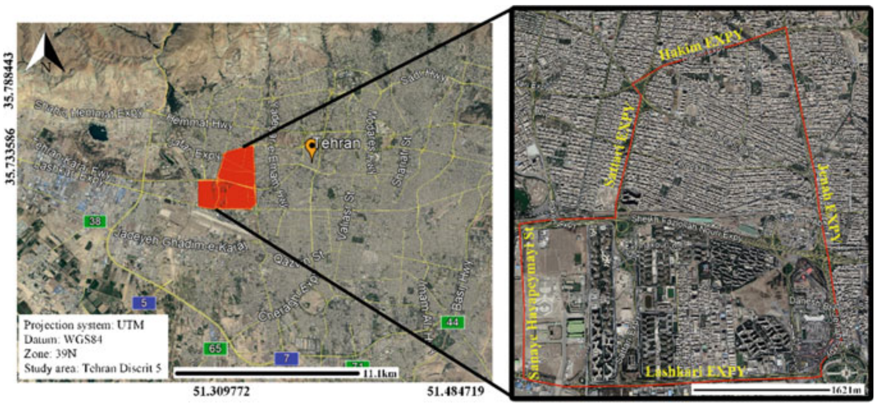



**Fig. 6** The study area

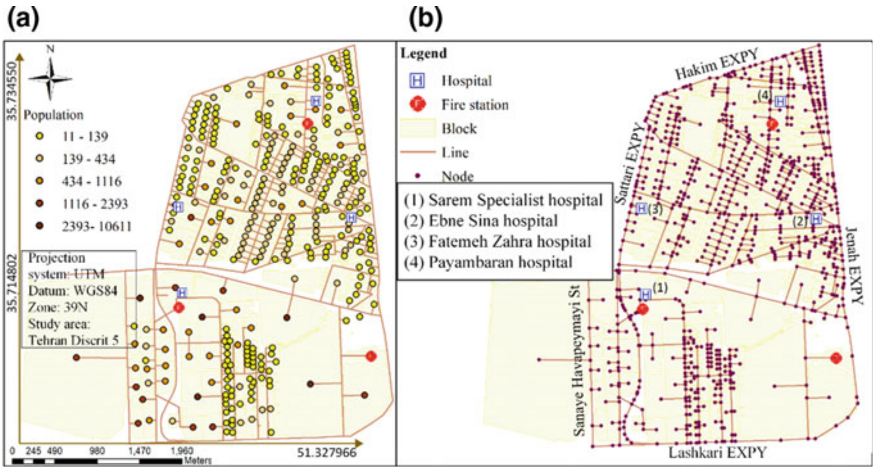



Fig. 7 **a** The population density in the study area, **b** The study area

are located in Tehran municipal District 5 that have 3, 4, 1, and 5 ambulances which are shown in Fig. 7.

The locations of emergency centers were acquired from Tehran municipality District 5. Also, the studied fire stations and population density of the study area are represented in Fig. 7. The travel time of the vehicles on the urban street network of Tehran municipal District 5 in 2017 is obtained from Municipality of Tehran Transport and Traffic Company.

In this paper, MWNVD and PSO-MWNVD allocation for the emergency center are investigated. The generated MWNVDs and PSO-MWNVDs for the studied

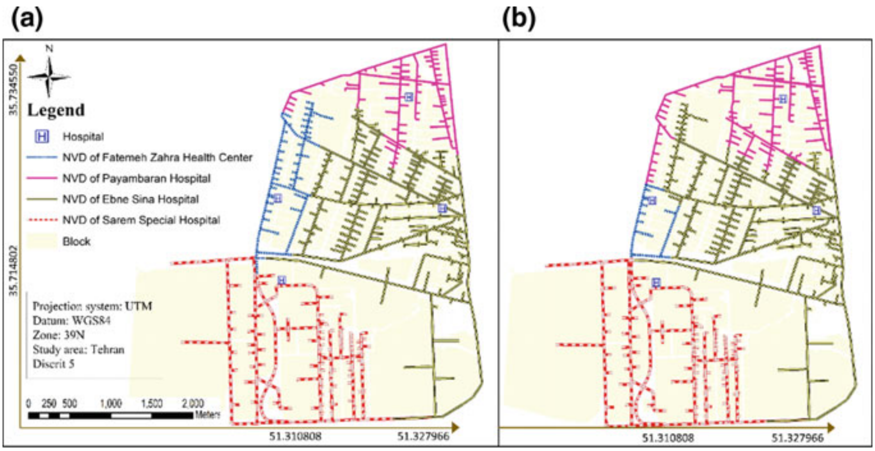



Fig. 8 **a** The generated PSO-MWNVDs, **b** The generated MWNVDs

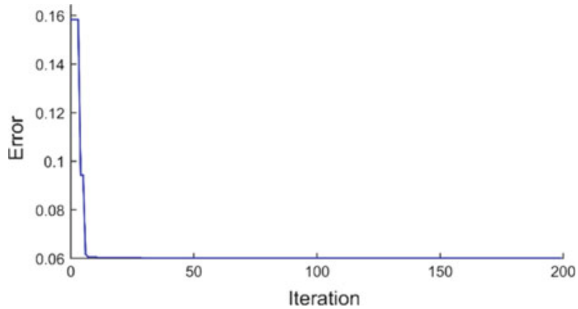



**Fig. 9** Diagram of the PSO optimization of the MWNVD

emergency centers are presented in Fig. 8. The optimum values for the parameters of PSO are determined in order to minimize *Er* for the VDs. The optimum values of $c_1$, $c_2$, $a$ and population size are selected to be 2, 2, 0.7 and 200, respectively. PSO is reached to the optimal mode of MWNVD in 200 iterations.

The changing of mean partial absolute error of PSO-MWNVD in 200 iterations is presented in Fig. 9. As shown in Fig. 9, the PSO algorithm with a relatively high speed in 12 iterations has achieved value of 6% error. While the *Er* error of MWNVD allocation is computed about 37%.


**Fig. 10** **a** The generated MWNVDs in Anylogic software, **b** The generated PSO-MWNVDs in Anylogic software

In this study, seventeen wounded with varying level of injuries and the random position were considered. The four above mentioned hospitals must be assigned to these wounded. The process of implementation is explained in the methodology section. The generated MWNVDs and PSO-MWNVDs in Anylogic are shown in Fig. 10. The initial VDs allocated to Sarem Specialist hospital, Ebne Sina hospital, Fatemeh Zahra health center and Payambaran hospital are called "$VD_1$", "$VD_2$", "$VD_3$" and "$VD_4$", respectively.

In the first type of the multi-agent rescue operation model, the six wounded are located in $VD_1$, the two wounded are located in $VD_2$, the three wounded are located in $VD_3$ and one wounded is located in $VD_4$. After delivering the help demand messages to the coordination center agent, the necessary actions are undertaken and

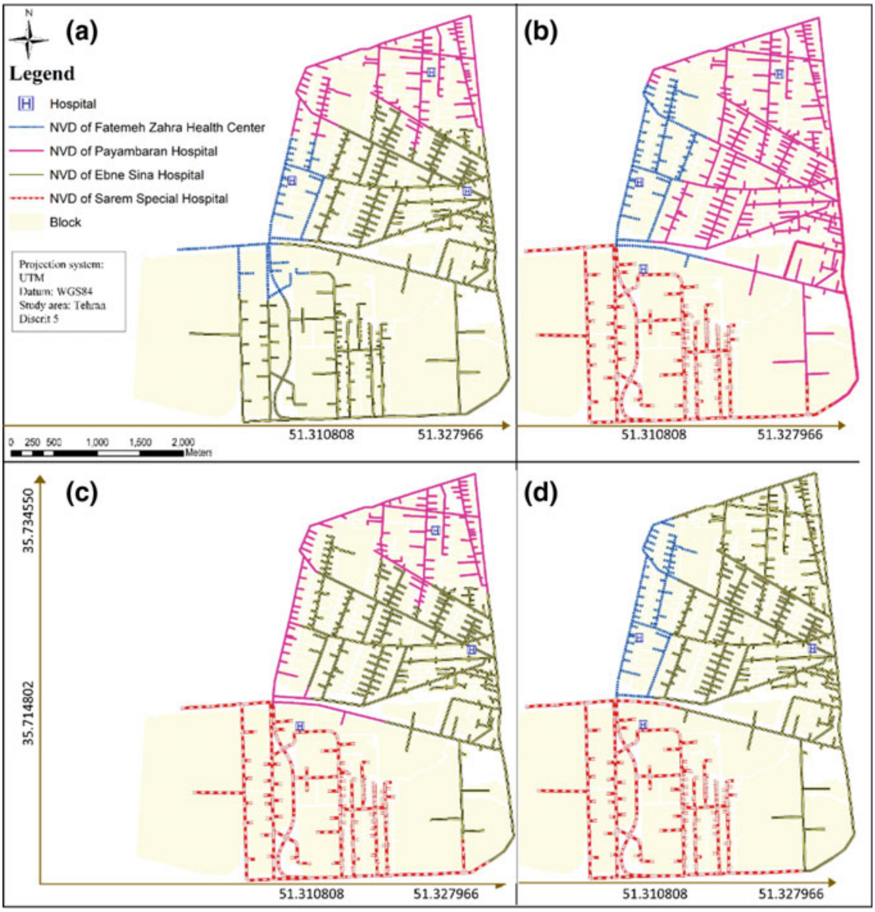



**Fig. 11** The generated PSO-MWNVD for the emergency centers that have the free ambulances when **a** the ambulances of the Sarem Specialist hospital, **b** the ambulances of the Ebne Sina hospital, **c** the ambulances of the Fatemeh Zahra health center and **d** the ambulances of the Payambaran hospital are not available

the ambulances dispatched to the demand locations according to the generated MWNVDs.

In $VD_1$, the number of demands is more than the ambulance numbers available in Sarem Specialist hospital. In this condition, the three wounded that have high priority are served first. The other three wounded wait until the ambulances become available again upon termination of their mission. When one of the ambulances have undertaken its mission, the high priority of these remained wounded are responded. Also, this trend is continued for the two remained wounded. The assignment process in $VD_3$ is similar to $VD_1$. Due to the fewer wounded than existing ambulances in $VD_2$ and $VD_4$, the wounded people get immediate medical assistance.

In the second and third types of the multi-agent rescue operation models, the location and the priority of the wounded are the same as the first type of the multi-agent rescue operation model. Four, two, five and one demands initially are located in $VD_1$, $VD_2$, $VD_3$ and $VD_4$ based on PSO-MWNVDs, respectively. Due to the more wounded than ambulances in $VD_3$, the re-allocation processing for Sarem Specialist, Ebne Sina and Payambaran hospitals were performed. After determining the new PSO-MWNVD for these three hospitals (Fig. 11c), the condition of the location of the remained three wounded against PSO-MWNVD are determined which are located in the PSO-MWNVD of the Payambaran hospital, Payambaran hospital and Ebne Sina hospital, respectively.

So, with this reallocation process, these five wounded persons are responded faster than the first type of multi-agent rescue operation model. In $VD_1$, $VD_2$ and $VD_4$, the ambulances are more than the wounded and the wounded who are located in theses VDs can receive medical assistance with no delay. After several minutes, a number of wounded send help demand to the coordination center agent. The

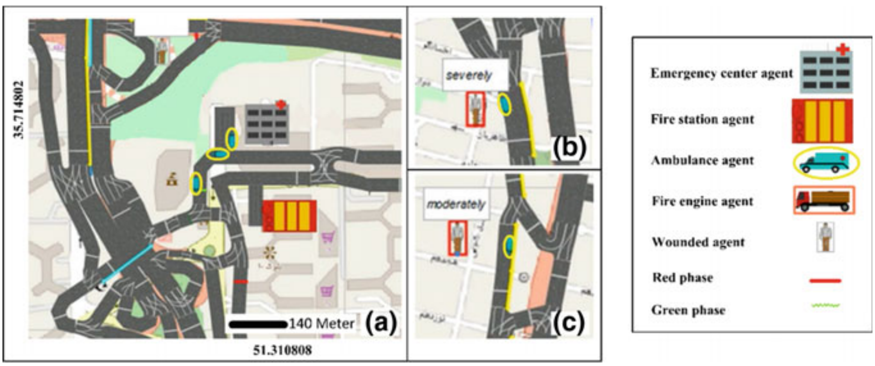



**Fig. 12** The actions of the ambulance agent. **a** Assignment of the tasks to the ambulances located in the Sarem Special hospital, **b** Reaching the ambulance to the wounded locations with severe injury levels, **c** Reaching the ambulance to the wounded with moderate injury levels

assignment process is again performed for the new demands. Figure 12 shows the ambulances allocation and actions in Anylogic simulation software.

Figures 13 and 14 show the ambulances and fire engines tasks and actions in the three types of the multi-agent rescue operation models in Anylogic simulation software.

The third type of multi-agent rescue operation model has some facilities for decreasing delay of the emergency vehicles in intersections and increasing the survival chance of the injured in comparison to the second one. The time

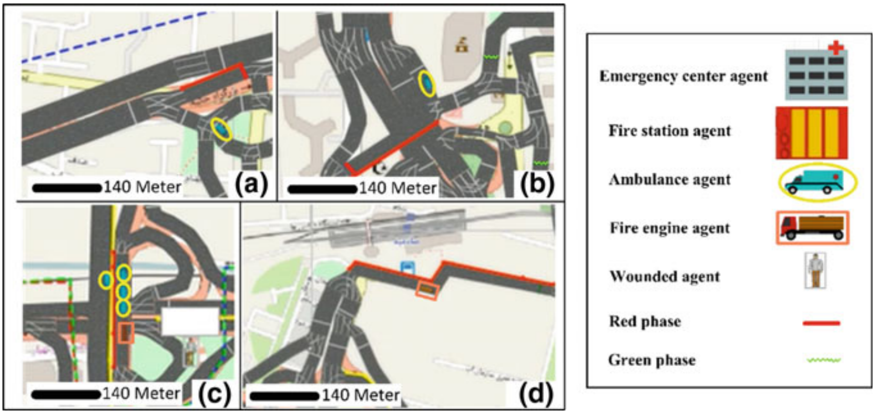



**Fig. 13** The actions of the ambulance and fire engine agents. **a** and **b** Updating of the ambulance route when faced with the blocked street in the second and third type of the multi-agent rescue operation model, **c** Resolving the blocked street by the fire engine in the first type of the multi-agent rescue operation model, **d** Resolving the blocked street by the fire engine in the second and third types of the multi-agent rescue operation models

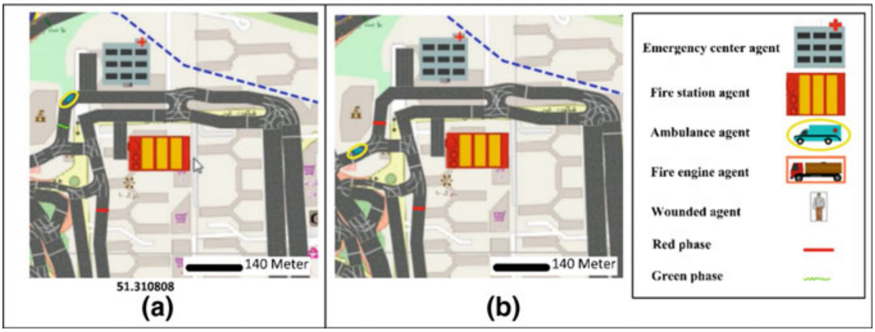



**Fig. 14** The actions of the ambulance agent in the third type of the multi-agent rescue operation model. **a** The traffic light phase becomes green during the passage of the ambulance, **b** The traffic light phase becomes red after the passage of the ambulance

performance of the third type of the multi-agent rescue operation model has the better result in comparison to other models.

Mustafa (2013) has shown that if the ambulance sends patient data to the hospital prior his/her arrival, the treatment preparation in the hospital will expedite about two minutes. These results are applied in the implementation of this research.

The diagram of response time of the ambulances to the injured persons and the diagram of the duration time of the ambulance missions for the first, second and third types of the multi-agent rescue operation models are shown in Figs. 15 and 16, respectively. In Figs. 15 and 16, the ambulance response time to the wounded persons for the first, second and third types of the multi-agent rescue operation models are demonstrated in red, green and yellow colours, respectively.

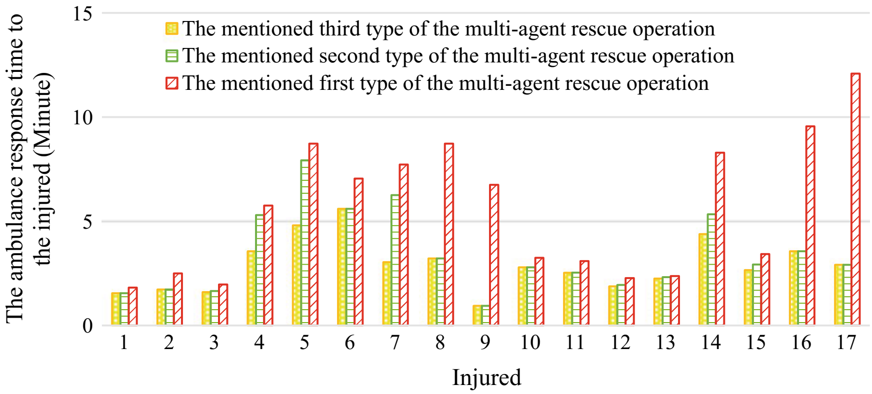



**Fig. 15** The diagram of arrival time of the ambulances to the injured location

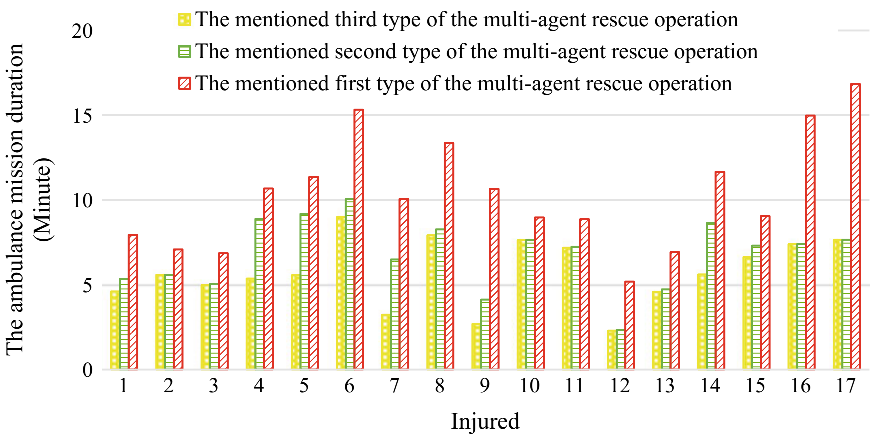



**Fig. 16** The diagram of the ambulance mission time in order to respond to the injured

**Table 1** The time improvement of the second and third types of rescue operation models compared to the first one

| | The second type of the multi-agent rescue operation model compared to the first one | The third type of the multi-agent rescue operation model compared to the first one |
|---|---|---|
| The improvement of the average response time of the ambulances to the injured (%) | 29.7 | 37.7 |
| The improvement of the average of the ambulance mission duration (%) | 32.6 | 42.5 |

According to the Table 1, the improvement of the average response time of the ambulances to the wounded persons and the average of the ambulance mission duration in the second and third types of the multi-agent rescue operation models in comparison to the first type of the multi-agent rescue operation model are computed as 29.7%, 32.6%, 37.7% and 42.5%, respectively.

## 5 Discussion

Using the Voronoi Diagram method to determine the service areas for each emergency center in many cases causes some emergency centers have the load more than their capacity and some of them have the shortage of the load, or if all of them have additional or lack of load, these amounts are not the same. Therefore, the PSO algorithm is used to solve these problems. The PSO-MWNVD algorithm improved the *Er* about 31% and decreased the *Er* to 6% at a relatively high speed. By applying the PSO on MWNVD in the second and third types of the multi-agent rescue operation models and wayfinding of emergency vehicles based on the minimum travel distance and time as well as utilizing smart city facilities, the ambulance performance for saving the injured is improved (Figs. 15 and 16). Updating the fire engine routes based on the blocked streets will prevent them from delaying. Therefore, the delivery of assistance to the wounded location will improve by removing obstacles quickly. Also, greening the traffic light in order to expedite the passage of the emergency vehicles from the intersections will cause the quick response to the injured and increase their survival probability. Therefore, consideration of the mentioned additional parameters in the third type of rescue operation model in comparison to the second one cause the average response time of the ambulances to the injured and the average of the ambulance mission duration decrease about 8 and 10% compared to the second one (Table 1).

## 6 Conclusion

Search and rescue of victims is an important issue in the disaster management. After occurring a disaster, the navigation of the first responders in the presence of obstacles and blocked streets for decreasing delay is necessary. Also, the efficient planning of appropriate allocation of the medical assistance to the disaster site is critical in response to the disaster.

In this study, the multi agent-based model for optimum allocation of the ambulances to the wounded locations according to the urban street network, population density, the number of ambulances exist in emergency centers, optimum wayfinding of emergency vehicles to the injured locations, the street blockage and smart city facilities to expedite the relief operation is proposed. The proposed rescue operation models using the multi agent-based model consists of coordination center, emergency centers, ambulances, fire stations, fire engines and the wounded agents.

After occurring the disaster, the wounded delivered their locations and initial symptoms to the coordination center agent. The rescue operation starts when the location and initial symptoms of the wounded are delivered to the coordination center agent. The severity levels of the patients' injury are directly relevant to the priority that should be given to each patient for receiving the medical assistance. The Bi-label Dijkstra algorithm is used for routing of the ambulances under the objective of minimizing travel length and time of the ambulances in the street network. The three types of multi-agent rescue operation models were implemented and their time performance for surviving the injured were compared. In the first one, the MWNVD allocation for determining the service areas of each emergency center is performed. After specifying the associated MWNVD for each wounded agent, the ambulance is delivered from the emergency center of the concerned MWNVD to the wounded agent location. In the case of high demand, if there is an available ambulance located in the emergency center, the allocation is performed, in order to prevent the injured remained helpless.

In the second type of the multi-agent rescue operation model, the PSO-MWNVD allocation specified the optimum service areas for the emergency centers. The ambulances routes are updated once facing with the blocked street. When the rescue operation workload exceeds the available ambulances of one or more emergency centers, the PSO-MWNVD allocation is performed again for another emergency centers as far as the new demanded wounded received medical assistance with no delay. Also, the information about the condition of the injured have been transferred to the hospitals prior to their arrival.

The third type of the multi-agent rescue operation model is similar to the second one with the difference that it has more smart facilities. Greening traffic lights when the passage of the emergency vehicles from the intersections and updating the route of the fire engine during its mission are considered in the third type of the rescue operation model compared to those of the second one. In PSO-MWNVD allocation, the partial difference between the estimated and expected population in VDs decreased to 6%. While the mentioned difference computed as 37% in the MWNVD allocation. The implementation results of the multi-agent rescue operation models show that the second type of the multi-agent rescue operation model decreased the average response time of the ambulances to the injured and the average of the ambulance mission duration about 29.7 and 32.6% compared to those of the first one, respectively. Also, the average response time of the ambulances to the injured and the average of the ambulance mission duration improved about 37.7 and 42.5% in the third type of multi-agent rescue operation model compared to those of the first one.

Our future work will be focused on more facilities of the smart city for improving the relief operation such as using the social media in the disaster management. The implementation of the proposed model by using other agent-based software platforms such as GAMA, Agent Analyst, RoboCup and their comparative analyses can be considered. The navigation of relief groups among moving obstacles can be investigated in the proposed model. Also, considering more agents such as police forces and Red Crescent agents in the multi agent-based model will bring the implementation closer to the reality.

## References

Alami-Kamouri S, Orhanou G, Elhajji, S (2017) Mobile agent service model for smart ambulance. In Cloud Infrastructures, services, and IoT systems for smart cities, Springer, pp 105–111

Alazawi Z, Alani O, Abdljabar MB, Altowaijri S, Mehmood R (2014) A smart disaster management system for future cities. In Proceedings of the 2014 ACM international workshop on wireless and mobile technologies for smart cities, ACM, pp 1–10

Andersson T, Varbrand P (2007) Decision support tools for ambulance dispatch and relocation. J Oper Res Soc 58(2):195–201

Aurenhammer F, Klein R (2000) Voronoi diagrams. Handb Comput Geom 5:201–290

Azimi S, Delavar MR, Rajabifard A (2017) Multi-agent simulation of allocating and routing ambulances under condition of street blockage after natural disaster. Paper presented at the international archives of the photogrammetry, remote sensing and spatial information sciences, SMPR and EOEC 2017, 7–10 Oct 2017

Azimi S, Delavar MR, Rajabifard A (2018) An optimized multi agent-based modeling of smart rescue operation, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Paper presented at the 2018 GeoInformation for disaster management (Gi4DM), Istanbul, Turkey, 18–21 Mar 2018

Bae JW, Shin K, Lee HR, Lee HJ, Lee T, Kim CH, Cha WC, Kim GW, Moon IC (2018) Evaluation of disaster response system using agent-based model with geospatial and medical details. IEEE Trans Syst Man Cybern Syst 48:1454–1469

Bai Q (2010) Analysis of particle swarm optimization algorithm. Comput Inf Sci 3(1):180

Bakici T, Almirall E, Wareham J (2013) A smart city initiative: the case of Barcelona. J Knowl Econ 4(2):135–148

Bandara D, Mayorga ME, Mclay LA (2014) Priority dispatching strategies for EMS systems. J Oper Res Soc 65(4):572–587

Billhardt H, LujaKk M, Sanchez-Brunete V, Fernandez A, Ossowski S (2014) Dynamic coordination of ambulances for emergency medical assistance services. Knowl Based Syst 70:268–280

Bostick NA, Subbarao I, Burkle FM, Hsu EB, Armstrong JH, James JJ (2008) Disaster triage systems for large-scale catastrophic events. Disaster Med Public Health Preparedness 2(S1): S35–S39
Chavoshi SH, Delavar MR, Malek MR, Frank A (2008) Landmark-based simulation for agent Wayfinding after earthquake
Djahel S, Jabeur N, Barrett R, Murphy J (2015) Toward V2I communication technology-based solution for reducing road traffic congestion in smart cities. Paper presented at the International symposium on Networks, computers and communications (ISNCC), IEEE, 13–15 May 2015a
Djahel S, Smith N, Wang S, Murphy J (2015) Reducing emergency services response time in smart cities: An advanced adaptive and fuzzy approach. Paper presented at the 2015 IEEE First international smart cities conference (ISC2), 25–28 Oct 2015b
Engelbrecht AP (2006) Fundamentals of computational swarm intelligence. John Wiley and Sons
Fiedrich F, Gehbauer F, Rickers U (2000) Optimized resource allocation for emergency response after earthquake disasters. Saf Sci 35(1–3):41–57
Ghomian Z, Yousefian S (2017) Natural disasters in the Middle-East and North Africa With a focus on Iran: 1900 to 2015. Health Emerg Disasters Q 2(2):53–62
Gong Q, Batta R (2007) Allocation and reallocation of ambulances to casualty clusters in a disaster relief operation. IIE Trans 39(1):27–39
Haghani A, Hu H, Tian Q (2003) An optimization model for real-time emergency vehicle dispatching and routing. Paper presented at the transportation research board 82nd annual meeting, Washington, DC, 12–16 Jan 2003
Hawe GI, Coates G, Wilson DT, Crouch RS (2015) Agent-based simulation of emergency response to plan the allocation of resources for a hypothetical two-site major incident. Eng Appl Artif Intell 46:336–345
Hirokawa N, Osaragi T (2016) Access time of emergency vehicles under the condition of street blockages after a large earthquake. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Paper presented at the 1st international conference on smart data and smart cities, 7–9 Sep 2016
Hooshangi N, Alesheikh AA (2018) Developing an agent-based simulation system for post-earthquake operations in uncertainty conditions: a proposed method for collaboration among agents. ISPRS Int J Geo-Inf 7(1):27
Ibrion M, Mokhtari M, Parsizadeh F, Nadim F (2015) Timescape of the earthquake disasters in Iran: the intricacies of earthquake time and earthquake disaster risk reduction. Geografiska Annaler Ser A Phys Geogr 97(1):197–216
Imawan A, Indikawati FI, Kwon J, Rao P (2016) Querying and extracting timeline information from road traffic sensor data. Sensors 16(9):1340
Karimi F, Delavar M, Mostafavi M (2009) Space allocation of educational centers using multiplicatively weighted voronoi diagram. In WG II/2, II/3, II/4: Workshop on Quality, Scale and Analysis Aspects of City Models
Li D, Shan J, Shao Z, Zhou X, Yao Y (2013) Geomatics for smart cities-concept, key techniques, and applications. Geo-spatial Inf Sci 16(1):13–24
Li X, Zhao Z, Zhu X, Wyatt T (2011) Covering models and optimization techniques for emergency response facility location and planning: a review. Math Methods Oper Res 74(3): 281–310
Lopez B, Innocenti B, Busquets D (2008) A multiagent system for coordinating ambulances for emergency medical services. IEEE Intell Syst 23(5)
Mustafa A (2013) Wireless applications of GIS in dynamic platforms: a case study in laptops and mobile phones. PhD Thesis, Mangalore University, India
Okabe A, Boots B, Sugihara K, Chiu S (1992) Spatial tessellations: concepts and applications of Voronoi diagrams. Chichester, UK
Pyrga E, Schulz F, Wagner D, Zaroliagis C (2008) Efficient models for timetable information in public transportation systems. J Exp Algorithmics (JEA) 12:2–4
Reitsma R, Trubin S, Mortensen E (2007) Weight-proportional space partitioning using adaptive Voronoi diagrams. Geoinformatica 11(3):383–405

Rezayan H, Najian A (2008) Land use allocation optimization using advanced geographic information analyzes. World Appl Sci J 3:136–142
Rini DP, Shamsuddin SM, Yuhaniz SS (2011) Particle swarm optimization: technique, system and challenges. Int J Comput Appl 14(1):19–26
Roozemond DA (2001) Using intelligent agents for pro-active, real-time urban intersection control. Eur J Oper Res 131(2):293–301
Rusell S, Norvig P (2003) Artificial intelligent: a modern approach
Sang TX (2013) Multi-criteria decision making and task allocation in multi-agent based rescue simulation. PhD Thesis, Japan Graduate School of Science and Engineering, Saga University, Japan
Santosa B (2006) Tutorial Particle Swarm Optimization. Kampus ITS, Sukolilo Surabaya, p 66
Serafini P (1987) Some Considerations About Computational Complexity for Multi Objective Combinatorial Problems. Recent Advances and Historical Development of Vector Optimization. Springer, Berlin, Heidelberg:222–232
Talarico L, Meisel F, Sorensen K (2015) Ambulance routing for disaster response with patient groups. Comput Oper Res 56:120–133
Ticha HB, Absi N, Feillet D, Quilliot A (2017) A solution method for the Multi-destination Bi-objectives Shortest Path Problem. Ecole des Mines de Saint Etienne, CMP, Gardanne, France
Wang Y, Colledanchise M, Marzinott A, Ogren P (2014) A distributed convergent solution to the ambulance positioning problem on a streetmap graph. IFAC Proc Vol 47(3):9190–9196
Wang z, Zlatanova S (2016) Multi-agent based path planning for first responders among moving obstacles. Comput Environ Urban Syst 56:48–58
Wood L (1974) Spatial interaction and partitions of rural market space. Mag Econ Soc Geogr 65 (1):23–34
Yang XS (2010) Engineering optimization: an introduction with metaheuristic applications. John Wiley and Sons
Yue Y, Marla L, Krishnan R (2012) An efficient simulation-based approach to ambulance fleet allocation and dynamic redeployment. Paper presented at the AAAI on artificial intelligence, 22–26 Jul 2012
Zhuang J, Bier VM (2007) Balancing terrorism and natural disasters—defensive strategy with endogenous attacker effort. Oper Res 55(5):976–991