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A New Approach for Modeling Spatio-Temporal Events in an Earthquake Rescue Scenario

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Abstract: This study explores the advantages of modeling spatio-temporal events in an earthquake scenario. For this purpose, the theory of Time Geography is assessed and extended such that rescue team can act more efficiently. Heuristic programming in an activity based manner is exercised to manage team activities in space and time. Rescue team is forced to perform several tasks in an earthquake event; this study focuses on modelling the activities of life-detecting, collapse-lifting and injured-transporting. In order to assess the model, a case study was simulated through normal and suggested methods. The comparisons between them have done through three different scenarios; fixed numbers of members, fixed number of members with 5 h work limitation and finally variable number of members with no time constraint. The statistical analysis on the results show an average of 27.22% improvement in groups' activities. This model can be implemented on Spatio-Temporal Geospatial Information System (GIS) and other researchers can develop it to manage the entire rescue team activities.

Key words: Rescue teams, spatio-temporal activities, time geography, heuristic programming, earthquake

INTRODUCTION

Many countries in the world, due to their location and geographical extents are prone to natural disasters particularly earthquakes. Such an issue makes the management of crisis and planning for rescue more important. Rescue operations include three levels: before disaster (prevention and preparation) during disaster (rescue) and after disaster (normalization) (Pine, 2006). In all rescue operations, it seems necessary to follow a comprehensive plan to provide enough resources; to demarcate the domain of operations, to cooperate effectively and to avoid parallel working.

Various studies have been performed to manage rescue works some of them are very specific and can handle only a reduced number of issues (Brower and Bohl, 2000; Bullock *et al*., 2006; Burby, 2002; Canton, 2007; Guniz *et al*., 2006; Haddow *et al*., 2006; McEntire, 2005; Pine, 2006; Schwab, 2003). The earlier studies put their emphasis on either space or time of a disaster. Rescue like other human activities requires considering spatial and temporal dimensions at the same time (Alesheikh *et al*., 2007). Any proper planning should then consider both dimensions for damage reduction in a way that the rescue teams can achieve their goals with maximum efficiency.

Hagerstrand (1970) presented a theory which became popular as Time-Geography. This theory makes it possible to model human activities in space and time and lets graphics to be shown on space-time axis. Hagerstrand (1970) has also presented two right-angled axes: X as the space and condition and Y as the time of activity. This theory was welcomed by many researchers so that they applied it in several spatio-temporal human models (Kwan, 2000; McBride *et al*., 2002; Miller, 2003, 2004, 2005; Miller and Shaw, 2001; Wang and Cheng, 2001; Yu, 2006; Yu and Shaw, 2007).

Considering the importance of rescue team activities after earthquake and their spatio-temporal nature as well as potential of time-geography in spatio-temporal human modeling, this study tries to model the rescue team activities in more real conditions. Nevertheless, this theory has some problems while facing dynamic phenomena; for example, when team members are changing temporally, modeling cannot be completed. The present study has solved such a problem by an innovative technique, which claims a new framework for earthquake rescue teams. The proposed framework can be implemented in a Geospatial Information System (GIS) and then various GISs' analytical modelling for optimum management will be accessible (Alesheikh *et al*., 2005).

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MATERIALS AND METHODS

Space-time model for developing rescue team management: Since rescue team activities are so vast that cannot be included in one study, this research considers the activities of three important teams: Life-detecting, collapse-lifting and injured-transporting teams.

Life-detecting, collapse-lifting and injured-transporting teams: The major responsibilities set for life-detecting team can be classified as searching, pointing and rescuing people under the collapse (Pine, 2006). The rescuers quick action can definitely be a great help to find the people buried under collapse. Therefore, searching for live people and pointing is more important than collapse-lifting team and should be given the first priority.

The major issues that are considered important to a collapse-lifting team are determined as preparing a location map, considering a dumpsite for the remains, finding a special space for the dead bodies and the injured, securing the site by cutting power, water and gas, recording number of wounded and dead people and finally collapse-lifting. It should also be mentioned that all collapse-lifting teams should have a pre-determined plan before entering into disastrous area (McEntire, 2005).

The most important tasks in injured-transporting team are divided into quick transporting of the injured to pre-determine medical centers and transporting the injured by helicopters or by vehicles (Haddow *et al.*, 2006).

Performance improvement of rescue teams in space-time: To achieve optimal management, it seems crucial for rescuing teams to have a close interaction. Therefore, besides considering time, a map of disastrous area is needed. In rescue operation, preparing a map of affected area is one of the measures taken before disaster i.e., prevention and preparation (Brower and Bohl, 2000). In this study, it is assumed that such a map has been prepared. It is also assumed that a vulnerable map shown in Fig. 1 is available, in which the region is divided into three zones: new, normal and old structure. So, the area can be divided into three destruction zones; high, average and low destruction area (Fig. 1).

Having determined the location and the amount of destruction, rescue operations and their flexibility should be ranked. The last step is the modeling on space-time domain. In the first phase, three activities of life-detecting team were presented on space-time axis using Time-Geography theory (Fig. 2).

In Fig. 2, it takes A time for the life-detecting team to reach the site and begin their task. Now, this group can keep on the tasks until time B. At the same time and based on the intensity of destruction, pointing should be started; afterward the first priority will be given to saving lives. In case the life-detecting team activities are done normally, three individual groups with separate tasks that are not able to help others would be needed. Using the model, team members can do their own task or once finished can help other teams.

The second team whose activities would be examined is collapse-lifting team. To manage their tasks, their activities are demarcated on time and space axes in a way that their priorities can be set (Fig. 3).

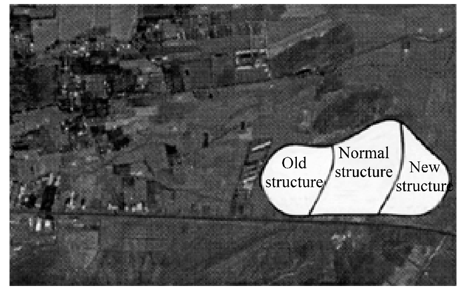

Fig. 1: Study area with various vulnerable sections

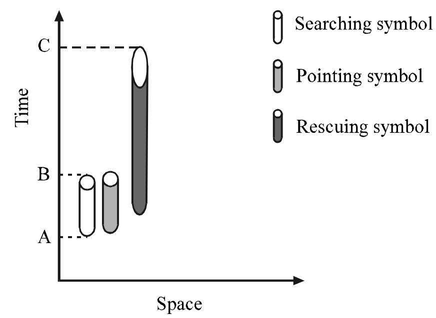

Fig. 2: Modeling of life detecting activities in space-time

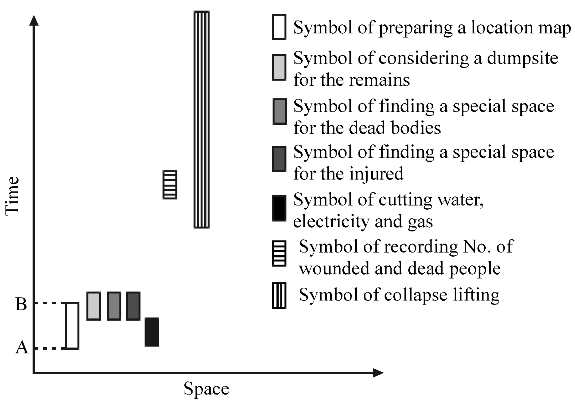

Fig. 3: Modeling of collapse lifting activities in space-time domain

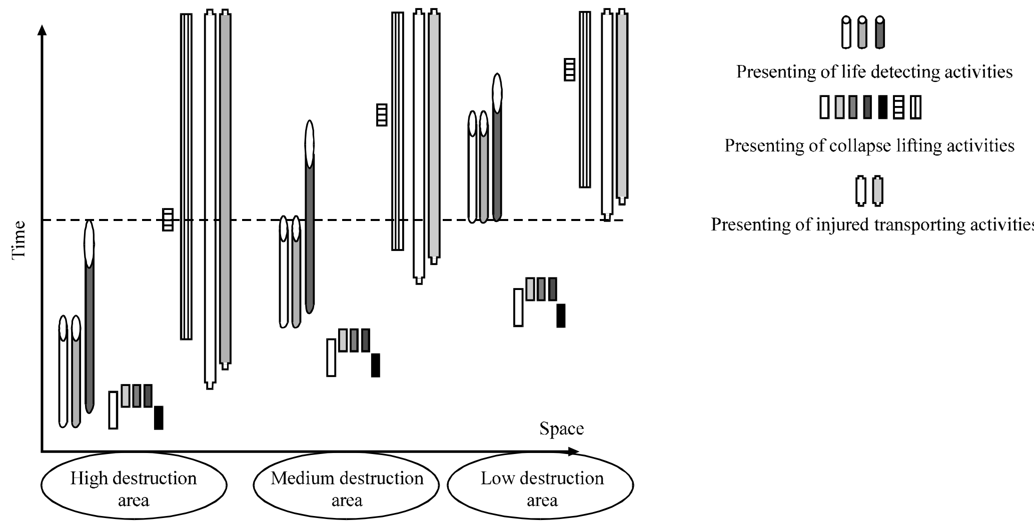

Fig. 4: Modeling life detecting, collapse lifting and injured transporting activities in all area, with respect to their space-time situations

In this model, it requires A time for map team members to get to the location and begin their job. This group is required to finish its job until point B in time. While mapping, others should take security measures by cutting water, electricity and gas. The next steps would be locating a space for dumping the remains, finding a place to keep the corpse, determining a location for the injured and finally collapse-lifting. Based on these two recent models, the activities of injured-transporting team can be modelled.

Spatio-temporal models can get close to reality when all the tasks in disastrous areas can be integrated. Figure 4 shows modeling all activities in different areas. In this model, activities in each team are shown separately. Horizontal axis (location) is divided into three sites: high, average and low risk areas. Vertical axis depicts the temporal order of performing activities.

To model the teams in entire region, the highly destructed areas should be put in priority. Here, the team members should be arranged in a way that life-detecting team measures should be done first to be able to save as many people as possible. Based on this model, the first tasks of life-detecting team is to find live people and point the highly destructed areas. On duty or after accomplishing their tasks, the team members can play effective roles on activities which are above the drawn line, depending on the physical conditions, type of activities and the importance of the remaining measures.

In Fig. 4, there is a line drawn from the top of an activity. This line indicates that team members having finished their task can participate the activities shown above the line depending on their boredom, remaining energy, type of profession, training experience and the needs in the given area. In the given model, team arrangement is the task of team moderator in the area; this director must be quite familiar with everyone's competence and capabilities for rescue team management in earthquakes. Using such models, it seems much more facilitating not only to arrange members' activity in space and time but also to transfer members within groups.

For instance, saving victims under ruins is a very cumbersome task, which requires lots of energy. In this case, a team director can draw a line on time axis in the desired hour and replace members by other teams. He can also arrange them in other low-energy activities shown above the line. This task can in turn increase team efficiency and rescue management. It is worth mentioning that, such efficiency can be achieved when the action plan is predetermined. Such transition is probable in many real conditions. The main reason is that the number of team members is not predetermined and as time passes more members are added to the team. In such dynamic condition the above model cannot handle changes efficiently.

In the present study, the researchers have used a heuristic programming in an activity based manner. In this case, a temporal variable has been assigned to each member. This variable varies based on the type of activities and the energy needed. When a person's time variable is finished, a fresher one replaces him or as the manager may desire would do some other activities with low energy consumption (Fig. 5).

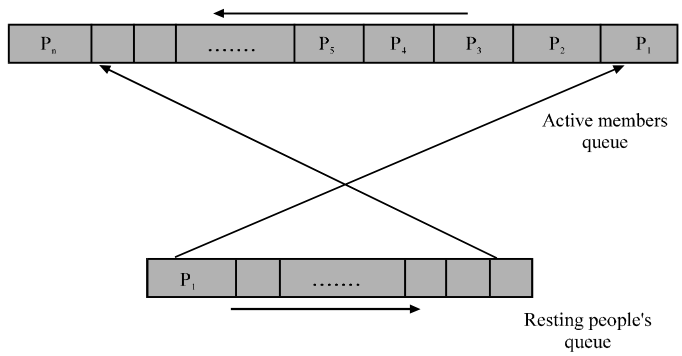

Fig. 5: Heuristic programming for dynamic management of members' transition

Practical assessment: Due to the lack of real situations, the researchers simulated the conditions in a given area. The selected study was done in August 2007 and its site was located in 5 km of Mashhad-Shandiz road in Iran covering 9 km^2. After earthquake destruction zones are demarcated as accurate as possible. This location was divided into three areas: high, medium and low destructions after the earthquake. This division would be much more accurate considering the common features in developing destruction maps (Fig. 1). In each area, the given collapses were formed due to the intensity of destruction in a way that they could only be removed by the team members.

The participants were divided into three life-detecting, collapse-lifting and injured-transporting teams and their activities were thoroughly monitored. The life-detecting team was formed by three searchers, three pointers and six savers. Collapse-lifting team also included two members to develop an early map, one member to locate the depot, one member to locate a space for the corpse, one member to locate a space for the injured, one member to serve the region by cutting electricity, water and gas, one member to record the injured and the dead and finally eight members to take collapses. In addition, injured-transporting team included six members to transport the given injured to the medical center quickly.

In this rescue operation, it is assumed that there was a predetermined plan in which there were no rooms for unexpected events. As it was impossible to have real persons as the victim, it is decided to have six pets, here cats. Of these cats, three were placed in high destruction area and one was put in low destruction area. This was done in a way that no harm could threaten the pets and no one in life-detecting team knows where they are.

At first operation was accomplished in a normal way without considering the study model. In this phase, all members simultaneously began the rescue operation in all mentioned areas. All activities were recorded including the type of activity, No. of members needed, the beginning and ending time, the amount of time needed at the operation site and the distance every member took for each activity. In the second phase, the activities and arrangements were accomplished based on the suggested model. In this phase, the data in the whole operation was accurately recorded to make a precise comparison possible. Table 1 and 2 show practical assessment in simulated area.

Three cases were designed and tested in this study:

- Team members were fixed until the end of operation. In this case, team management was much easier and there was an accurate supervision over the teams' activities. The major problem was, however, tiredness and work condition which made the members' operation and their output decreased after a while. In spite of this problem, the suggested model shows an improvement for rescue, collapse-lifting and injured-transporting teams 19.7, 17.67 and 19.67%, respectively over normal method (Table 3, 6). Numbers in the tables, indicate performance average in normal and suggested model, respectively
- Team members were fixed with 5 h time constraints. Again, the suggested model showed improvement over the traditional one in teams' management up to 21.37, 21.67 and 19.7%, respectively (Table 4, 6)
- The No. of members varies based on the manager decision. This case is the major contribution of the study and accommodates temporal changes. The suggested model is more efficient as it shows

Table 1: Rescue operation done normally

Type of activity	No. of members needed			Operation site			Beginning time			Ending time			The amount of time needed			Distance every member		
	Destruction area			Destruction area			Destruction area			Destruction area			Destruction area			Destruction area		
	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
Searching	3	3	3	Same priority (A)			7.00	7.00	7.00	8.30	8.10	8.00	1.30	1.10	1.00	Whole area	Whole area	Whole area
Pointing	3	3	3	A	A	A	7.00	7.00	7.00	8.30	8.10	8.00	1.30	1.10	1.00	Whole area	Whole area	Whole area
Rescuing people under the collapse	6	6	6	A	A	A	7.00	7.00	7.00	13.30	12.00	10.30	6.30	5.00	3.30	Whole area	Whole area	Whole area
Preparing a location map	2	2	2	A	A	A	7.00	7.00	7.00	8.10	8.00	7.50	1.10	1.00	0.50	Whole area	Whole area	Whole area
Considering a dumpsite for the remains	1	1	1	A	A	A	7.00	7.00	7.00	7.50	7.40	7.30	0.50	0.40	0.30	Whole area	Whole area	Whole area
Finding a special space for the dead bodies	1	1	1	A	A	A	7.00	7.00	7.00	7.50	7.40	7.30	0.50	0.40	0.30	Whole area	Whole area	Whole area
Finding a special space for the injured	1	1	1	A	A	A	7.00	7.00	7.00	7.50	7.40	7.30	0.50	0.40	0.30	Whole area	Whole area	Whole area
Securing the site by cutting power water and gas	1	1	1	A	A	A	7.00	7.00	7.00	7.30	7.25	7.20	0.30	0.25	0.20	Whole area	Whole area	Whole area
Recording No. of wounded and dead people	1	1	1	A	A	A	7.00	7.00	7.00	14.00	12.30	11.00	7.00	5.30	4.00	Whole area	Whole area	Whole area
Collapse-lifting	8	8	8	A	A	A	9.00	9.00	9.00	16.00	14.30	13.00	7.00	5.30	4.00	Whole area	Whole area	Whole area
Trans-porting the injured	6	6	6	A	A	A	7.00	7.00	7.00	15.00	13.10	11.35	8.00	6.10	4.35	Whole area	Whole area	Whole area

Table 2: Rescue operation using the suggested model

Type of activity	No. of members needed			Operation site			Beginning time			Ending time			The amount of time needed			Distance every member		
	Destruction area			Destruction area			Destruction area			Destruction area			Destruction area			Destruction area		
	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
Searching	3	With respect to the model and in different situation is various		First priority (A)	Second priority (B)	Third priority (C)	7.00	8.30	9.40	8.30	9.40	10.40	1.30	1.10	1.00	Whole area	Parts of area	Parts of area
Pointing	3	„	„	A	B	C	7.00	8.30	9.40	8.30	9.40	10.40	1.30	1.10	1.00	Whole area	Parts of area	Parts of area
Rescuing people under the collapse	6	„	„	A	B	C	7.10	8.40	9.50	13.40	14.30	15.10	6.30	5.50	5.20	Whole area	Parts of area	Parts of area
Preparing a location map	2	„	„	A	B	C	7.00	8.30	9.40	8.10	9.30	10.30	1.10	1.00	0.50	Whole area	Parts of area	Parts of area
Considering a dumpsite for the remains	1	„	„	A	B	C	7.30	8.50	10.10	8.20	9.30	10.40	0.50	0.40	0.30	Whole area	Parts of area	Parts of area

Table 2: Continued

Type of activity	No. of members needed – Destruction area: High	Medium	Low	Operation site – Destruction area: High	Medium	Low	Beginning time – Destruction area: High	Medium	Low	Ending time – Destruction area: High	Medium	Low	The amount of time needed – Destruction area: High	Medium	Low	Distance every member – Destruction area: High	Medium	Low
Finding a special space for the dead bodies	1	„	„	A	B	C	7.30	8.50	10.10	8.20	9.30	10.40	0.50	0.40	0.30	Whole area	Parts of area	Parts of area
Finding a special space for the injured	1	„	„	A	B	C	7.30	8.50	10.10	8.20	9.30	10.40	0.50	0.40	0.30	Whole area	Parts of area	Parts of area
Securing the site by cutting power water and gas	1	„	„	A	B	C	7.00	7.30	7.55	7.30	7.55	8.15	0.30	0.25	0.20	Whole area	Parts of area	Parts of area
Recording No. of wounded and dead people	1	„	„	A	B	C	13.10	13.50	15.00	14.00	14.30	15.30	0.50	0.40	0.30	Parts of area	Parts of area	Parts of area
Collapse-lifting	8	„	„	A	B	C	9.00	10.00	10.45	15.30	15.50	16.00	6.30	5.50	5.15	Parts of area	Parts of area	Parts of area
Trans-porting the injured	6	„	„	A	B	C	8.15	9.25	10.25	16.15	16.40	17.15	8.00	7.15	6.50	Parts of area	Parts of area	Parts of area

Table 3: Result of the first scenario

Situation	Fixed members with no time constraints (%)								
Teams	Life-Detecting team (LD)			Collapse-Lifting team (CL)			Injured-Transporting teams (IT)		
Destruction area	High	Medium	Low	High	Medium	Low	High	Medium	Low
Normal method	40	57	66	41	56	68	19	29	34
Suggested method	63	74	85	60	72	86	42	47	52

Table 4: Result of the second test

Situation	Fixed members with 5 h limit (%)								
Teams	Life-Detecting team (LD)			Collapse-Lifting team (CL)			Injured-Transporting teams (IT)		
Destruction area	High	Medium	Low	High	Medium	Low	High	Medium	Low
Normal method	21	37	45	24	38	49	10	17	25
Suggested method	42	57	68	46	59	71	29	38	50

Table 5: Result determination for third situation

Situation	Changing members with no time limitation (%)								
Teams	Life-Detecting team (LD)			Collapse-Lifting team (CL)			Injured-Transporting teams (IT)		
Destruction area	High	Medium	Low	High	Medium	Low	High	Medium	Low
Normal method	31	46	55	29	47	55	11	20	31
Suggested method	73	85	95	70	88	96	55	63	70

Table 6: Comparison of three scenarios with the normal rescue team activities

Situations	Fixed members with no time			Fixed members with 5 h limitation			Changing members with no time limitation		
Teams	(LD)	(CL)	(IT)	(LD)	(CL)	(IT)	(LD)	(CL)	(IT)
Normal method operations, average in all area	54.34	55.00	27.33	34.30	37.00	17.34	44.00	43.67	20.7
Suggested method operations, average in all area	74.00	72.67	47.00	55.67	58.67	39.00	84.33	84.66	62.7
Betterment (%)	19.70	17.67	19.67	21.37	21.67	21.66	40.33	40.99	42.0
Improving in each situation		19.01			21.56			41.10	
Total improvement					27.22				

LD: Life-Detecting team, CL: Collapse-Lifting team, IT: Injured-Transporting teams

40.33, 40.99 and 42% improvement in rescue, collapse-lifting and injured-transporting teams, respectively (Table 5, 6)

RESULTS AND DISCUSSION

Comparing the three situations, it is clear that the suggested model improves performance in all situations: 19.1, 21.56 and 41.01%, respectively. The overall average for three situations was estimated as 27.22%, which proves an improvement over traditional model. Table 6 present a summary of statistics to make a better and more precise comparison between the three case studies.

CONCLUSION

The occurrence of earthquake threatens many countries in the world. Man has no role in this occurrence but his integrated treatment can reduce suffering and improve the condition. The challenge, however, is to consider time and space simultaneously in modeling.

In the present study, rescue team activities in three life-detecting, collapse-lifting and injured-transporting teams are modeled in a new and multidimensional space that considers time and space inseparable. Heuristic programming in an activity based manner were integrated with time geography to support dynamism. Three scenarios were planned to assess the results of the suggested model. They are; fixed members with no time constraint, fixed members with 5 h limitation and variable members with no time limitation. The statistical analysis of the results indicate that applying the suggested model, efficiency increased up to 27%. Implementing the model on Spatio-Temporal GIS, determining the frame of all rescue team activities, applying dynamic scheduling, queuing theory and space-time prism are considered as future works.

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