A BIOLOGICALLY-INSPIRED OPTIMIZATION ALGORITHM FOR URBAN EVACUATION PLANNING IN DISASTER MANAGEMENT

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ABSTRACT: One of the most important issues in the management of disasters that caused by natural phenomena in urban areas is how to evacuate inhabitants of hazardous areas to safe areas. Optimal allocation of capacities in safe areas to inhabitants leads to effective decision making by inhabitants for displacement to safe areas in evacuation process. Effective decision making in disaster management is so noticeable and can decrease losses of disasters. Optimal allocation of capacities in safe areas is so complicated especially in urban areas that are so inhibited. Nevertheless, Up to now, there is no effective method to solve this problem. Allocation of capacities in safe areas closely resembles bee forager allocation amongst flower patches to optimize nectar influx. So, for first time in this paper, a novel algorithm that inspired from bee colony foraging behaviour and its characteristics used to create an optimization algorithm to solve emergency evacuation problem. Proposed method used to solve evacuation problem for an urbane area and Results of proposed method indicate that this method is so capable to solve emergency evacuation of inhabitant in hazardous urban areas to safe areas.
1. INTRODUCTION

The resident in the stricken area takes evacuation center to the evacuation center for the security of the body for the reasons for uneasiness etc. to coming to difficult use by the dwelling, and the continuing disaster at a lot of natural disasters including the seismic hazard. Generally, facilities that seem to be safe it at the disaster beforehand are scheduled as a evacuation center and it becomes the condition of the evacuation center establishment in the evacuation center there is no fear of a damage of scheduled facilities little and fire in case of, for instance, the earthquake. The condition investigates the damage situations of various places including the Evacuation center by the staff of the municipality and those who support it immediately after the disaster, and is decided in the emergency center based on the information. However, the evacuation center thought to be safe is expected not to be able to be used with the passage of time by the occurrence of the typhoon and the earthquake at a simultaneous period and aftershocks’ continuing like the "The Niigataken Chuetsu-oki Earthquake in 2007". The rescue supply supply's when the disaster occurs being done promptly and appropriately leads to the damage reduction as it relates to the stricken area resident's support, and restoration is done smoothly as a result. But the supply of the support goods begins after resident's safety is secured. It is given priority to make the resident take evacuation center to a safer place, and to defend resident's life. Than the first in this text, to support the municipality and the resident of the disaster, it reports on the details for the construction of the resident evacuation support function using Geographical Information System.

2. URBAN EVACUATION PLANNING

McEntire defines evacuation as "the movement of people away from potential or actual hazards for the purpose of safety" (2007, 122). Evacuation can be used in response to protect lives from the effects of natural disasters including major storms, floods, hurricanes, volcanic eruption, wildfire, or earthquake (Zelinsky, et al. 1991; Cova and Church 1997). Evacuation can also be used to protect lives in response to a variety of technical, industrial, or human-caused incidents such as warfare, terrorism, bomb threats or detonations, fire, and hazardous material releases (Zelinsky, et al. 1991). One study has estimated that technological disasters have led to 25 evacuations involving over 5,000 or more people over a 15-year period, worldwide (Sorensen, et al. 2004, 5).

Evacuation decisions, or lack thereof, following several technological incidents in the late 70s and early 80s including the reactor accident at Three Mile Island near Middletown, Pennsylvania, in 1979, and the toxic gas release from the Union Carbide subsidiary in Bhopal, India, in 1984, have also attracted the attention of evacuation researchers (Zelinsky, et al. 1991). For instance, though there were emergency evacuation plans for the Middletown community; neither the plant managers nor local or state authorities implemented the plans when they were needed most during this response (Zelinsky, et al. 1991). As a result terrified citizens were left to make sense of confusing media reports and to fend for themselves (Zelinsky, et al. 1991).

Great number of impacted inhabitants, limitation on number and capacity of safe areas and different number of inhabitants of affected areas are the major challenges presented in a large scale urban evacuation. So, the variables used to determination of urban evacuation problem include number of inhabitants of hazardous areas, capacity of safe areas and spatial location of areas and distance between hazardous and safe areas that are the most important factors in disaster management (Kevany, 2005). The optimal objective established based on the shortest evacuation time and the most number of evacuees. The objective function defines by equation 1.

\[
Y = \sum_{j=1}^{S} \sum_{i=1}^{B} \left( \frac{P_i}{d_{i,j}} \right) \tag{1}
\]

where, \(S\) is the number of safe areas, \(B\) is the number of hazardous areas, \(d_{i,j}\) is the distance between hazardous area \(i\) and safe area \(j\) and \(P_i\) is the population of hazardous area \(i\). Equation 2 restricts the sum of evacuees allocated to the safe area \(j\) with respect to its capacity.

\[
\sum_{i=1}^{B} PA_{i,j} \leq C_j \tag{2}
\]

where, \(C_j\) is the capacity of safe area \(j\) and \(PA_{i,j}\) is the number of people of hazardous area \(i\) allocated to the safe area \(j\). Equation 3 states that all the allocated capacity to a hazardous area is equal to number of inhabitants.

\[
\sum_{j=1}^{S} CA_{i,j} = P_i \tag{3}
\]

where, \(CA_{i,j}\) is the allocated capacity of safe area \(j\) to hazardous area \(i\). Biologically-inspired computation is an umbrella term for different computational approaches that are based on principles or models of biological systems. This class of methods such as evolutionary algorithms, ant colony optimization, and swarm intelligence complements...
traditional techniques in the sense that the former can be applied to large-scale applications where little is known about the underlying problem and where the latter approaches encounter difficulties. Therefore, bio-inspired methods are becoming increasingly important in face of the complexity of today's demanding applications. In general, the classical optimization techniques have difficulties in dealing with global optimization problems. One of the main reasons of their failure is that they can easily be entrapped in local minima. Moreover, these techniques cannot generate or even use the global information needed to find the global minimum for a function with multiple local minima. The interaction between computer science and optimization has yielded new practical solvers for global optimization problems, called meta-heuristics. The structures of meta-heuristics are mainly based on simulating nature and artificial intelligence tools. Meta-heuristics mainly invoke exploration and exploitation search procedures in order to diversify the search all over the search space and intensify the search in some promising areas. During last decade, a new kind of approximate algorithm has emerged which tries to combine basic heuristic methods in higher level frameworks aimed at efficiently and effectively exploring a search space. These methods are nowadays commonly called meta-heuristics. In summary we could say that meta-heuristics are high level strategies for exploring search spaces, using different methods.

4. PROPOSED EVACUATION PLANNING BASED ON BEE COLONY OPTIMIZATION

Meta-heuristics are used for combinatorial optimization in which the search-space of candidate solutions grows exponentially as the size of the problem increases. This often leads to computation times too high for practical purposes. Thus, the use of approximate methods to solve CO problems has received more and more attention during recent years.

4.1 Bee Colony Optimization

Artificial bee colony algorithm is one of the most important algorithms that inspired from the bee colony foraging behaviour and proposed by karaboga (2005). In this algorithms food sources represent solutions of the problem. The nectar amount of food source corresponds to the quality of solutions. Another algorithm that inspired from foraging behavior is Bees Algorithm and proposed by Pham et al. (2005). This algorithm performs a kind of neighborhood search combined with random search and can be used for both combinatorial optimization and functional optimization. Quijano and Passino(2007 a,b) proposed a model of honey bee social foraging that used for solving a class of optimal resource allocation problems. Lemmens et al. (2007) proposed a multi agent algorithm inspired by the behavior of biological bees. The algorithm combines both recruitment and navigation strategies. Teodorovic et al. (2006) proposed bee colony optimization that each bee makes a series of local moves and in this way construct a solution. Common characteristics between bee colony foraging behavior and resource allocation problem motivate to propose a method based on this behavior to determine urban evacuation problem.

4.2 Proposed Method

In proposed method hives represent safe areas, food sources represent hazardous areas and bees as agents represent partial capacity of safe areas. The purpose of proposed method is optimal allocation of capacity of safe areas to hazardous areas by devoting agents as partial capacity of safe areas to inhabitants of hazardous areas. The optimal allocation aims at evacuating and displacing the most number of people to the safe areas in the shortest possible time. So, greater number of inhabitants in hazardous area makes it more important and agents have more interest to devote to that area and less distance between safe and hazardous areas makes agents more interested to devote to that area. Flowchart of algorithm is illustrated in figure 1. In initial stage all agents are located in the safe areas and are unemployed. To initialize algorithm, all agents select a hazardous area randomly, devote to that area and become employed agents. Agents based on the distance to safe areas and the number of people in hazardous area, evaluate attractiveness of hazardous area. Attractiveness of hazardous area $z$ for agent $i$ in safe area $k$ calculated by equation 4.

$$F^i_z = (E^z)^{\alpha} / (d^z)^{\beta}$$

where, $E$ is number of people in hazardous area, $d$ is distance between safe and hazardous areas, $\alpha$ is significant level of number of people in hazardous area and $\beta$ is significant level of distance between safe and hazardous areas. Afterward, agents back to the safe areas and participate in the first decision making process. Each agent spends some time duration to start decision making that calculated by equation 5.

$$t^i_k = 1 / F^i_k$$

where, $t^i_k$ is the time duration that agent $i$ in safe area $k$ spends to start first decision making. Based on equation 4,
agents that devoted to the more attractive areas start first decision making sooner.

![Flowchart of proposed method](image)

In first decision making process based on the amount of total allocated capacity to the hazardous area that is equal to all agents devoted to that area, employed agents decide to continue or abandon the area. In this process if amount of total allocated capacity is more than number of people in hazardous area then agent abandon that area and become unemployed and if amount of total allocated capacity is less than number of people in hazardous area then agent continue the process and capacity of safe area reduced equal to partial capacity of agent. If agent decides to continue the process, it will participate in the second decision making process. Based on the attractiveness of the devoted hazardous area, every agent decides whether to abandon the devoted area, become unemployed agent and update capacity of safe area or continue and recruit the other agents before returning to the hazardous areas. Agent is more likely to abandon devoted hazardous area if its attractiveness is low compared to others. The probability $r_i$ of following devoted area is adjusted based on lookup table 1.

**Table 1: look up table for adjusting the probability of following devoted area**

<table>
<thead>
<tr>
<th>Probability rating</th>
<th>$r_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F &gt; L$</td>
<td>% 98</td>
</tr>
<tr>
<td>$.9 * L =&lt; F &lt; L$</td>
<td>% 90</td>
</tr>
<tr>
<td>$.75 * L =&lt; F &lt; .9 * L</td>
<td>% 80</td>
</tr>
<tr>
<td>$.6 * L =&lt; F &lt; .75 * L</td>
<td>% 60</td>
</tr>
<tr>
<td>$F &lt; .6 * L$</td>
<td>% 50</td>
</tr>
</tbody>
</table>

where, $F$ is attractiveness of hazardous area and $L$ is average attractiveness of all employed agents in safe area. Agents that decide to continue the process share information of devoted area to the other agents for certain time duration to recruit them. The recruitment is proportional to attractiveness of the safe area. The time duration to share information defined by equation 6.

$$TD = p_i^k \times \min \{1, C_j\}$$  \hspace{1cm} (6)

where, $C_j$ is the remaining capacity of safe area $j$ and $p_i^k$ defined by equation 7.

$$p_i^k = F_i^k / F^k$$  \hspace{1cm} (7)

where, $F_i^k$ is attractiveness of proposed area and $F^k$ is total attractiveness of proposed areas. Unemployed agents have two options to continue process. In first option, unemployed agents can become scout and find new areas around safe area. By this behaviour areas that are not explored can be considered by scout agents. In the second option agents can become onlooker and consider information shared by employed agents, select an attractiveness area and become employed agents. When all agents become employed they back to safe areas and participate in decision making processes. Algorithm terminates when all the inhabitants in hazardous areas covered by safe areas and fitness function of agents do not change noticeably.

**5. IMPLEMENTATION AND CONSIDERATION**
Three examples present and optimized to illustrate the use of the proposed method in optimizing urban evacuation problem and demonstrate its unique capabilities. Dijkstra algorithm used to find path and distance between safe and hazardous areas. In the first case, number of all inhabitants is more than total capacity of safe areas. Result of method is illustrated in figure 2(a). As illustrated in figure 2(a), proposed method is capable of distributing and allocating capacity of safe areas to inhabitants of hazardous areas. Because of shortage of capacity of safe areas, result of method is based on priority of hazardous areas for safe areas and some inhabitants remained unallocated. Figure 2(b) illustrates allocated and unallocated inhabitants. As illustrated in figure 2(c), as algorithm progressed, cost function for agents that is reverse of equation 1, reduced and algorithm terminated when it does not change notably. Rapid convergence and use of explorative agents illustrate that the proposed method is efficient and global convergence.

In the next case, a safe area is added to the previous case and result of method is illustrated in figure 3(a). Adding a new safe area changed allocation of capacity of safe areas in first case.

In the second case priority of hazardous areas changed and some inhabitants allocated to different safe areas in comparison to first case. Figure 3(b) illustrates allocated and unallocated inhabitants. Figure 3(c) illustrates rate of convergence of method. In the next case, total capacity of safe areas is greater than total number of inhabitants in hazardous areas. Result of algorithm is illustrated in figure 4(a). As illustrated in figure 4(b), all people allocated to safe areas. Figure 4(c) illustrates Rate of convergence of the method.

Figure 2 - Result of method in first case

Figure 3 – results of method in second case

Figure 4 - results of method in third case
In the last case, in comparison to previous one capacity of safe areas increased and effect of change in capacity of safe areas considered. Result of algorithm is illustrated in figure 5(a). Differences between figures 5(a) and 4(a) represent effect of added capacity. As illustrated in figure 5(b), all people allocated to safe areas. Added capacity in the last case improves quality of evacuation process in comparison to previous one and each safe area has enough capacity and finally remained some capacity for all safe areas. Consequently, each safe area allocated its capacity to the most preferable inhabitants of hazardous areas. So, inhabitants will be displaced to safe areas in shorter travel time. Figure 5(c) illustrates the rate of convergence of method.

6. CONCLUSIONS AND RECOMMENDATIONS

This paper proposes and evaluates a novel method to solve evacuation problem in urban areas in order to preparedness in disasters. Results of method indicate that the method is capable of providing robust evacuation plan and demonstrate promising results in minimizing travelling time from the affected areas to safety. Three factors include number of people in hazardous areas, capacities in safe areas and spatial location of areas and distance between hazardous and safe areas considered and different states of urban evacuation discussed.

REFERENCES


