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AN APPLICATION OF GENETIC ALGORITHM TO EVACUATION ROUTE PLANNING FOR ICT-BASED DISASTER PREVENTION DESIGN AIMING AT REAL-WORLD IMPLEMENTATION

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Abstract. *Recently, a concept of disaster prevention design (DPD) based on information and communication technology (ICT) is proposed, and various kinds of attempts have been carried out so far. From the viewpoint of such ICT-based DPD, evacuation route planning is one of the crucial topics in case of emergency. Therefore, genetic algorithm (GA) is employed in this study, and a route planning task is tried for aiming at real-world implementation. A key aspect taken into account here is how to reduce the computational load through drastic pruning-based empirical simplification. As a result of some computer simulations, whose model area is Hizen-Hamashuku in Kashima City, it is found that the proposed method is effective.*
Keywords: Evacuation route planning, Genetic algorithm (GA), ICT-based disaster prevention design (DPD), Pruning-based empirical simplification, Solution candidate

1. **Introduction.** Recently, we have quite a lot of natural disasters, e.g., earthquakes, typhoons and volcano eruptions, and such situation will not be changed near future. Once they hit our living area, it is unavoidable for us to suffer from severe damage. Also, artificial disasters including fire are serious problems. Then, a concept of disaster prevention design (DPD) based on information and communication technology (ICT) is proposed recently, and various kinds of attempts have been carried out. Such trials of ICT-based DPD cover various kinds of fields, and it is summarized in [1]. Among them, evacuation route planning is one of the crucial topics in case of emergency. It can be seen as one of combinatorial optimization problems, so several techniques including i) round robin, ii) neural networks, and iii) genetic algorithm (GA) are considered so far.

In the previous studies, a GA-based technique inspired by the Darwin's evolutional theory is introduced to some model cities [2, 3]. It is true that a basic idea is working well, but its computational time is too large to implement. Therefore, how to save the computational time is one of tough problems to be solved, and a rough approximation is introduced for dealing with an upcoming real-world problem in this study.

In the following part, an overview of previous studies is described in Section 2. Secondly, some computer simulations are carried out for aiming at real-world implementation in Section 3. Thirdly, discussion is made on how to develop this international research joint project near future in Section 4. Finally, conclusions from this study are summarized in Section 5.

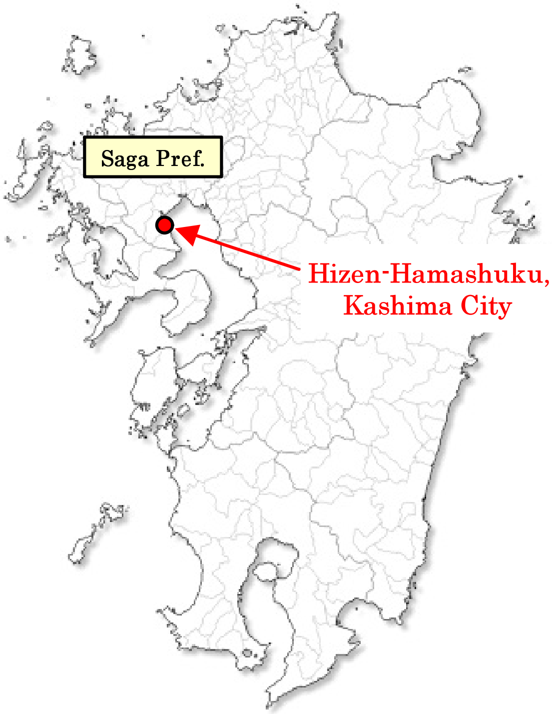


Figure 1. Location of Kashima City in Kyushu Island

2. **Overview of Previous Studies.** In order to cope with this problem, we have examined several issues step by step. At first, a route planning task with multiple goals is tried based on the evolutionary manner [2]. Its primal objective is to find out the shortest pathway to the nearest goal, but to find out alternative semi-shortest pathways to the other goals is also considered. The GA-based technique is adopted here, because parallel search strategy using multiple individuals seems to be suitable for this kind of task. At that time, a simple model city consisting of only ten nodes, each of which corresponds to an intersection, is adopted.

As a next step, its basic idea is applied to a 40-node model city, which is a model area called Hizen-Hamashuku in Kashima City, Saga Prefecture, Japan. Its location is shown in Figure 1. It is a preservation district of historic buildings with narrow streets, and most residents are elder people. According to some computer simulations, it is confirmed that the proposed framework is effective, but its computational time is too large to implement [3]. Its major reason comes from a policy which we have adopted, i.e., we want not to miss any potential solution candidates. Therefore, it leads to a simple idea as follows.

- A candidate route consists of all nodes, selected one-by-one serially from the given start point.
- Once the node assigned to the goal is selected, its individual is regarded as being able to find out a refuge place successfully. Then, the remaining part is not considered any more.

From the viewpoint of efficiency, it is easy to imagine that the heading part of the gene sequence, corresponding to an effective pathway from the start to the goal, makes relatively smaller and smaller as the number of nodes in the model city increases, unless its arrangement is quite narrow. Based on the above-mentioned considerations, how to reduce computational load is essential in this study.

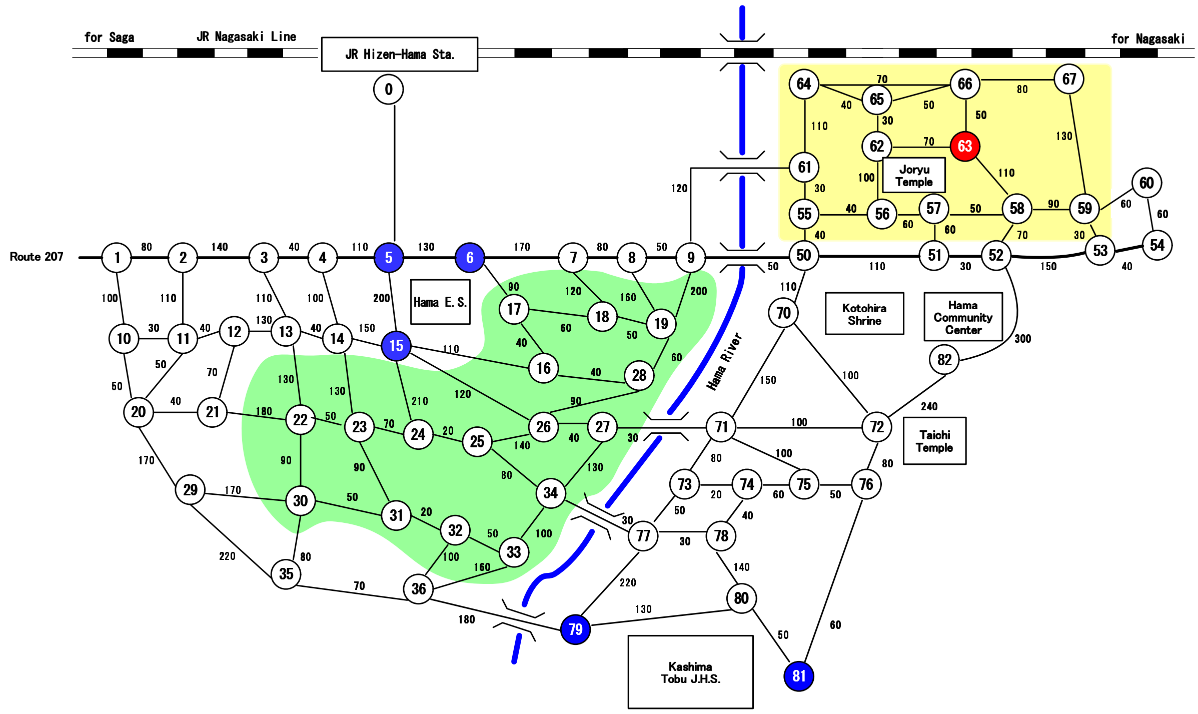


Figure 2. A graph-based representation of Hizen-Hamashuku in Kashima City, Saga Prefecture, Japan

3. Computer Simulations.

3.1. **Model area.** First of all, about 70 intersections are selected from the map of Hizen-Hamashuku, and its graph-based representation is summarized in Figure 2. Each node has its own ID number, e.g., #0-36 for the river-west district, #50-81 for the river-east district. In this map, two refuge places, i.e., i) Hama Elementary School (#05, #06, #15), and ii) Kashima Tobu Junior High School (#79, #81), are provided in advance. As an example, a start point is set in the river-east district at #63. For reference, the total length to each goal is identical, so how to decide a heading direction at #50, in front of the bridge, is a key issue in this study.

3.2. **Methods.** Under the above-mentioned condition, a GA-based evacuation route planning task is carried out. As shown in Figure 3, it is an ordinary way.

Step 1: *initialize* all individuals' gene expression in the 1st generation,
Step 2: *evaluate* all individuals' score based on the pre-defined fitness function,
Step 3: unless the pre-defined criterion is not *satisfied*, move on to the next step,
Step 4: *select* individuals based on their scores through *elimination* or *duplication*,
Step 5: prepare all individuals in the next generation through *crossover* of gene sequence,
Back to Step 2.

Following these steps, 200 individuals (parents) in the 1st generation are provided randomly just taking account of any actual connections between arbitrary two nodes. This simplification can be seen as something like pruning for the node selection. Each individual consists of 15 genes, as shown in Figure 4, and their arrangement corresponds to the intersections one-by-one serially from the start point to one of the refuge places. This is a drastic simplification, because it implies that only 15 nodes, i.e., about 1/5 number of total nodes, are enough to reach the goal. Such a simple assumption is just an empirical conviction which we have observed in the previous study [3]. So, there is no guarantee for success.

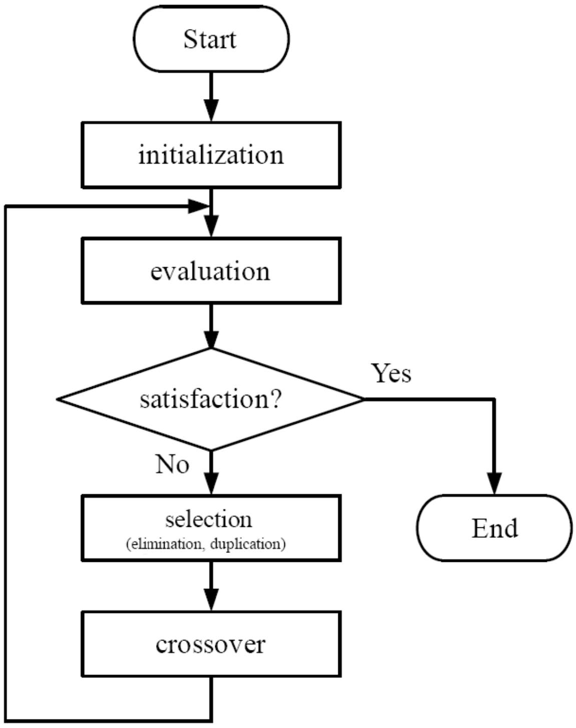


Figure 3. Genetic algorithm (GA)

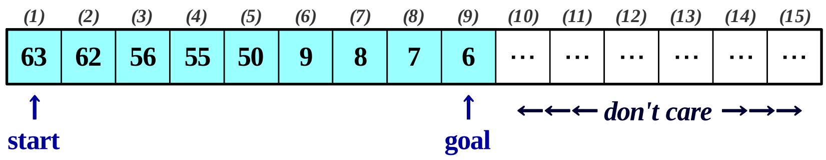


Figure 4. Representation of gene sequence

By the way, once its heading part of each gene sequence reaches either goal successfully, the remaining part is ignored. The evolutionary procedure is repeated for 100 generations, unless all individuals find out their pathway to the goal. A fitness function is defined as $e = 1/L$, where L is a total length of each solution candidate, and it is maximized through the evolutionary procedure. It is noticeable here that an extra penalty factor X is added to the actual length L when an individual cannot reach any goals.

In the selection phase, the worst four individuals (2%) are eliminated at first, and then the best four individuals (2%) are duplicated instead. In contrast to the previous study, a cyclic crossover [4] is useless, because not all nodes are contained in each individual. Thus, another method for crossover is introduced as follows.

- All individuals are aligned in descending order based on the fitness function e.
- A crossover node in the best individual (parent) is determined randomly.
- The other individual, which has the same node at the same position, is searched from the bottom to the top.
- If such an individual (another parent) is found fortunately, two new individuals (offsprings) are generated through exchanging the remaining part of gene sequences.
- On the contrary, if no matching individuals are found, it is succeeded to the next generation as it is.

This is an outline of how to develop the next generation adopted in this study. Any mutations are not considered here for simplicity.

Table 1. Results of computer simulations. The best solution in each trial.

trial	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
length	600	600	600	600	600	600	600	600	600	600
type	i, ii	i, ii	ii	i	i	ii	ii	i, ii	i	i

3.3. **Results.** In this study, ten different kinds of initial sets consisting of 200 individuals are prepared, and a task to find out any pathways starting from the node #63 is tried. According to the preliminary observations, there are two options, whose total length is 600, in this task as follows:

i) <#63> - #62 - #56 - #55 - #50 — #09 - #08 - #07 - <#06> : Hama ES
ii) <#63> - #62 - #56 - #55 - #50 — #70 - #72 - #76 - <#81> : Kashima Tobu JHS

Although there are some other options, they are divided into two above-mentioned cases depending on their directions.

An overview of the computer simulation results is summarized in Table 1. It is clear that all trials can reach the goal ($^{10}/_{10}$), and all of them can find out the shortest pathway successfully ($^{10}/_{10}$). In any trials, it took only several seconds. As can be seen in Table 1, some trials discover the pathways heading for Hama ES ($^{4}/_{10}$), and others discover the pathways heading for Kashima Tobu JHS ($^{3}/_{10}$). Furthermore, the rest trials discover the both pathways simultaneously ($^{3}/_{10}$).

In the previous study, for reference, only the river-west district consisting of about 40 nodes in Figure 2 is adopted, and 6000 individuals are prepared for each generation from 1 to 6000. Although the assigned task is completely different and the computer used for simulations is different, it took about a few hours to complete in each trial. As a result, eight out of ten trials find out the shortest pathway ($^{8}/_{10}$). The rest trials find out the pathway to Hama ES, but they are not the shortest ones.

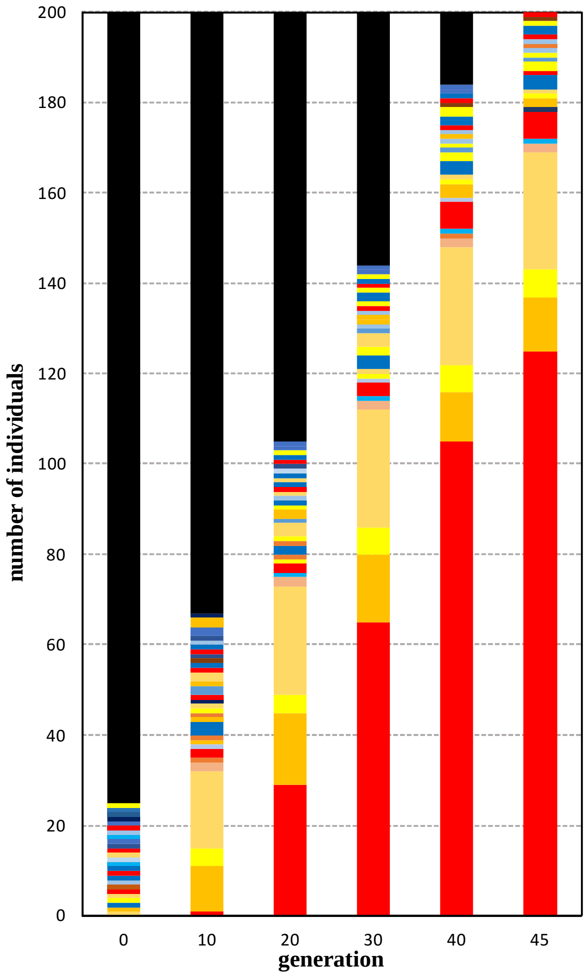
It is addressable here that computational load becomes much lighter than the previous study, even though the size of model area is increased. And, it is also found that the drastic simplification which we have introduced here is applicable to finding out the shortest pathways.

As mentioned above, there are two major cases: one is only a single type of solutions (either i or ii) found, while the other is multiple types of solutions (both i and ii) found. In order to make clear its mechanism, development process of each case is investigated from the viewpoint of both distribution of all solution candidates and number of individuals. Also, final distribution of all candidates after evolution is investigated.

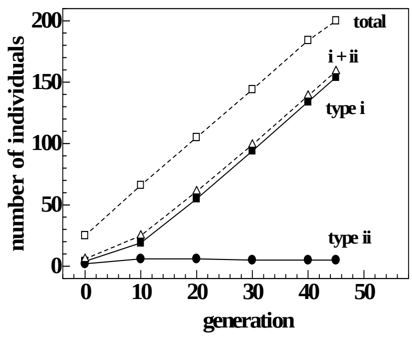
According to Figure 5, an example of some trial, it is clear that most individuals (black ones) cannot find out any solution candidates in the early stage of evolution. However, a few individuals can discover sub-optimal solutions (colored ones, and their variations correspond to different solutions) accidentally, and some well-fitted individuals among them are developed rapidly with generations. Table 2 shows the final distribution of all candidates after the 45th generation. At first glance, it is obvious that the dominant solutions correspond to the shortest pathway, and the other solutions also correspond to semi-shortest pathways. However, in this trial, most of them are heading for Hama ES.

Figure 6 shows an example of another trial. Its profile is quite similar to the previous case in Figure 5, but most individuals are divided into two kinds of solutions. This might be a natural consequence of the variety observed in the initial set. Although not equal, there are two solutions heading for two refuge places as shown in Table 3.

4. **Discussion.** From the viewpoint of ICT-based DPD, there are several research groups in this international joint research project. Each group is working on its own topics depending on the members' expertise. In our case, as mentioned above, evacuation route planning and any applications based on the soft computing technology are charged with.



(a) Distribution of all candidates



(b) Number of individuals

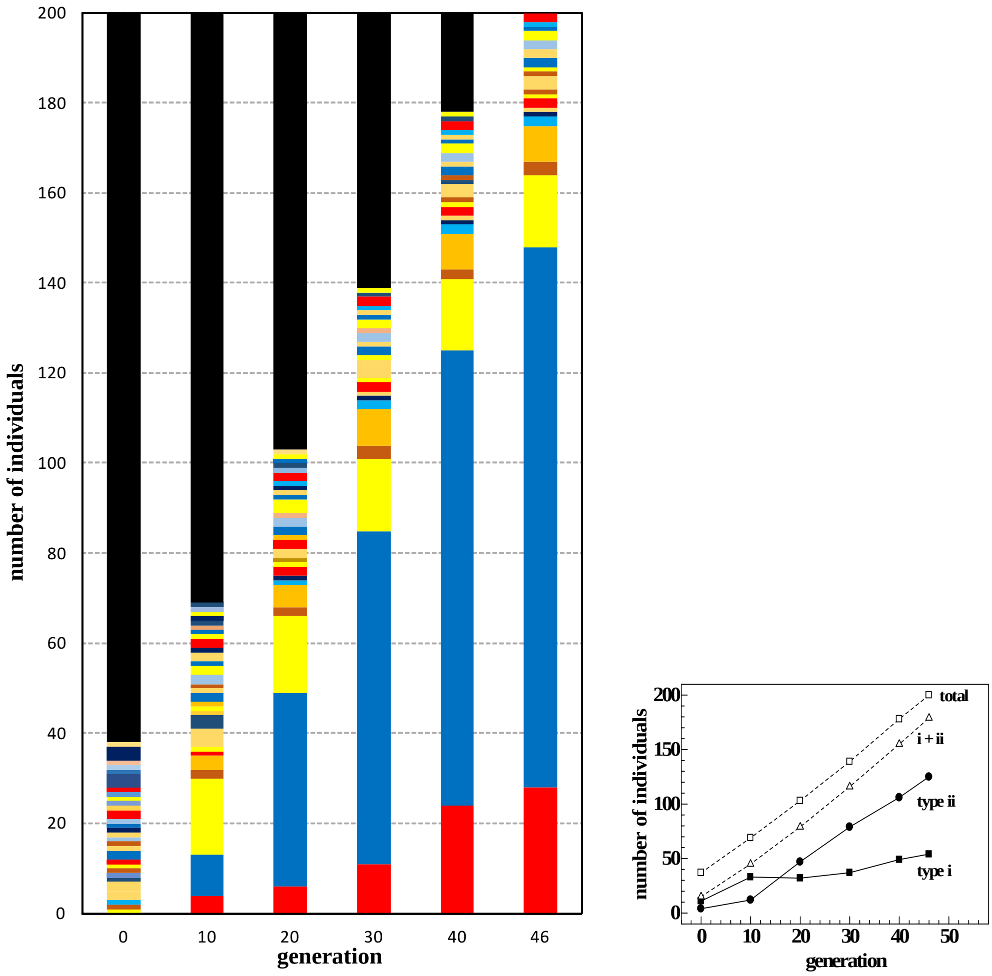
FIGURE 5. Results of computer simulations [I] – in case of single solution found

TABLE 2. Distribution of all candidates after evolution [I] – single solution found

length	type		individuals
	i	ii	
600	√		125
		√	0
650	√		12
660	√		6
670	√		26
680	√		2
720		√	1
750	√		6
780		√	1
820	√		2
830	√		1
840	√		1
860		√	3
880	√		1

length	type		individuals
	i	ii	
910	√		2
930		√	1
940	√		1
		√	1
950	√		1
1010	√		1
1030	√		1
1060		√	1
1090		√	1
1130	√		1
1140	√		1
1200	√		1
total	191	9	200

Then, the GA-based approach is adopted here to search for optimal pathways to the given refuge places. One of the problems so far is the fitness function designed to just minimize the total length of each acquired pathway. Taking account of real-world implementations,



(a) Distribution of all candidates (b) Number of individuals

Figure 6. Results of computer simulations [II] – in case of multiple solutions found

Table 3. Distribution of all candidates after evolution [II] – multiple solutions found

length	type i	type ii	individuals
600	√		28
		√	120
650	√		16
		√	0
660	√		3
670	√		8
		√	2
680		√	1
700	√		1
710	√		2
720	√		1
730	√		1
750	√		3

length	type i	type ii	individuals
810	√		1
820	√		1
860		√	2
910	√		2
930		√	2
960	√		2
		√	1
990		√	1
1060		√	2
total	69	131	200

the fitness function must be designed not only based on the length but also its risk passing through. Furthermore, how to evacuate smoothly and safely for local residents is also an important issue. In order to realize this idea, for example, changing a proposal of evacuation route plan depending on his/her situation, i.e., a custom-made evacuation route proposal system, might be useful. After discussing from the various points of view, further considerations are required to brush up this concept.

5. **Conclusions.** In this paper, evacuation route planning is tried from the viewpoint of ICT-based disaster prevention design (DPD), and the genetic algorithm (GA) is adopted to find out an optimal pathway. The key aspect proposed here is how to reduce the computational load through the drastic simplification. As a result of computer simulations, it is found that the above-mentioned simplification is applicable, and it is concluded that the proposed method is effective. In order to brush up this concept, further considerations from the viewpoint of real-world implementations as mentioned above must be accelerated.

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