Building A Dynamic Path Choice Model of Flooding Evacuation in Urban Area

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***Abstract*—This research has shown the difficulties associated with the GIS and the flooding evacuation path search through the huge searching space generated during the network analysis process. This research also presents an approach to these problems by utilizing a search process whose concept is derived from natural genetics. Genetic Algorithms (GA) have been introduced in the optimization problem solving area by Holland (1975) and Goldberg (1989) and have shown their usefulness through numerous applications. We apply GA and GIS to choice flooding evacuation path in metropolitan area in this study. We take the region of Shiji city in Taiwan for case. The part of this research could be divided into four parts. (i), is to set the population of GA operation. (ii), is to choose crossover and mutation. (iii), is to calculate the fitness function of each generation and to select the better gene arrangement. (iv), is to reproduce, after evolution, we can establish flooding Evacuation Path (EP) that more reflect really human action and choice when flood takes place. Fourth, we compare the Network Analysis (NA) and GA calculation, and establish real model of EP choices model to choice flooding evacuation path.**

***Index Terms*—Genetic Algorithms, Network Analysis, GIS, Evacuation Path.**

I. Introduction

When the flood occurs in the metropolitan area, the evacuation path choice model plays an important part for us to study or discussion. We need to provide proper Evacuation Path Model (EPM) to people, and decrease the damage; however, in the process of analyzing the EPM, we usually plan it as the shortcut. Although obtaining shortest distance and the time motionless situations, but it is not necessarily the best path, and it lacks the dynamic consideration [8]. So when we study the problem of the EPM, we can not just think about the shortest distance. We must to think about the most suitable EP, and provide other EP to face the situation of the EPM.

Beside these foregoing questions, the time series is the important part of this study. The depth of the water was changed by the time series. The range of the inundation will change along with the time status [2]. Thus, on the planning of evacuation path and precaution node, there are something need to be considered. First, the dangerous degree of flood in the area needs to be examined. Second, the time efficiency of evacuation path needs to be evaluated. In order to achieve the function of flood-avoided, not only the condition of the location itself but also the condition of the environment needs to be considered [5]. We must base on the different flood frequency of the time conditions to make the dynamic evacuation path and achieve the real function to against the disaster.

So we can search the EP by the GA and NA to find the optimization model to help us soon get the global optimum [1] and the least cost of different weight in this study.

II. Theory

The theoretical basis of the research included GA, GIS, Network Analysis (N) and disaster prevention theories. The biological evolution aroused GA, which is a kind of optimization search model within natural choice process. It operates by the way of the encoding gathered by parameter and gets rid of restrictions of seeking space analysis. For this reason, we can get the Global Optimum faster, and prevent it become the Local Optimum. Therefore, the study uses the GA and NA to goes on the choice of the dynamic flooding evacuation path. By the way, we can display the more real human behavior and find the least cost EP by the dynamic program of the data base in time. Receiving the batter population, we combine the function of the GIS Spatial Analysis, under the disaster prevention theories, it can present a more safe model that near to the behavior of the really evacuation in mankind. The structure of combined GA with GIS like figure 1

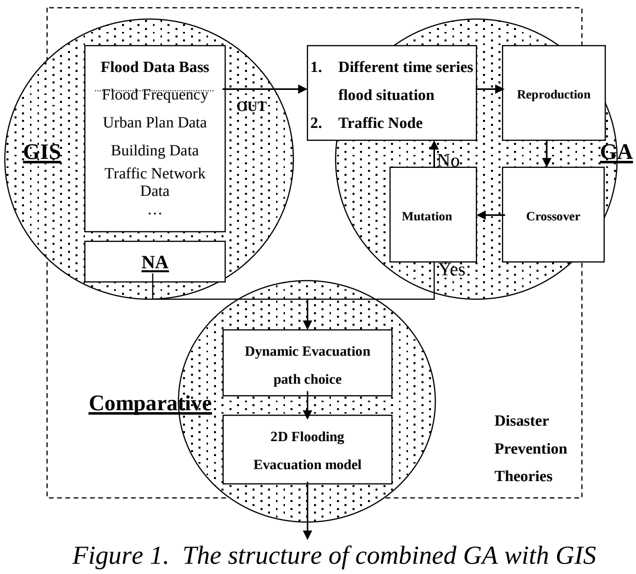

Figure 1. The structure of combined GA with GIS

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A. Person streaming theory

The walk speed will be closed to normal speed if there is enough space. On the contrary, if there is not enough space, walk speed will be slow down even closed to stop depending on the increasing density. Dr. Tanaboriboon and Dr. Guyano think about that walk speed and body characteristics of western is differ with oriental. At the center street of Bangkok city in Thailand it was studied to survey location the ambulation of people [9]. They divide service level of ambulation into 6 rankings (A, B, C, D, E and F). And they convert walk speed base on the relationship of density and discharge like Table 1.

B. Dynamic program

We can use dynamic programming to find the suitable evacuation path. With the dynamic programming, we can establish the decide node in the time and the node of the traffic street network. And we can combine the attribute of the traffic network and some important information with GA to find the optimum EP.

TABLE 1
THE WALKING SERVICES LEVEL THAT TANABORIBOON AND GUYANO ESTABLISHED.

Services level	Density (Person / Square metre)	Velocity (Metre /Second)	Flow (Person / Metre * Second)	Condition
A	≦0.42	≧1.12	≦0.47	* Don't generate conflict each other
B	0.43~0.63	1.06~1.11	0.48~0.67	* The velocity and flows become slightly slow
C	0.64~1.02	1.00~1.05	0.68~1.02	* The pedestrian needs to adjust the velocity and directions
D	1.031~1.54	0.88~0.99	1.03~1.35	* Difficult to change the direction and cross
E	1.55~2.70	0.62~0.87	1.36~1.68	* Extremely difficult to change the direction and cross
F	>2.71	<0.61	>1.69	* Can't reverse direction and cross

C. Network Analyze

Network Analyze is a way can get the optimum solution by some designate standards of the traffic network database. Networks are making up with some information which are expressing with points and lines. It is suitable to modeling roads, pipes, facilities and finds the optimum answers.

D. Genetic Algorithms

John Holland proposed genetic algorithms (GA) in 1795. This is an optimization of problem solving and technologic of machine learning. It is enlightenment from creature evolution process. The answer of every problem expresses a chromosome that present an individual creature. A group of creature were evolution by Darwin's evolutionism compete and select. The fitting creature exists that present the good solution survival the bad eliminates through competition. The new solution of new generation also to model creature propagates by survival's individual copulation and mutation [3].

There are four different points between GA and traditional way of optimization and search. (1). GA deals with whole set of solution, not only solution itself. (2). The search of GA starts from a group of population fitting well and scattering beginning, not from a point. (3). GA is objective function, not differentiation or others assist knowledge. (4). GA leads the direction of search only by hands around rule of probability [10].

It is a series process of self adjusts in search control of design reasoning of GA [7]. The combination of design reasoning rules could be a chromosome of one of EP solution. Every set of chromosome is whole result of inference path generated by probability. These evolution from parents and generate next generation were selected by environment conditions. Those are constantly adjusted through heuristic rules and search strategy, stop until solution fit need. The whole process of evolution is the process of finding out answer. The final result of inference paths, evaluative rules and solution is important knowledge of EP. There are three process follow:

1. Reproduction

The probability of copy from parents is derived from fitness degree of the chromosome. The common method is Roulette Wheel Selection by the percentage of its fitness degree of the chromosome over summarization of all fitness degree. That is the more high fitness degree the more opportunity to duplicate from parents.

2. Crossover

After reproduction the crossover provide for exchange chromosomes between mother generations in order to get the befitted chromosome from parents [4].

3. Mutation

It may change some genes form some chromosomes to avoid lost the befit information by reproduction and crossover in the genetic process. So we can extend the searching space to escape from the local optimum to the global optimum.

III. ESTABLISH THE DYNAMIC EVACUATION PATH MODEL

A. Geographic Information System

We use GIS to establish the system which combining the data base of the flood information. At first, we search and collect the flooding data base. And than we infer the estimating model, and set up the in put and out put of the system. About the base data, we collect the urban planning map and some correlating data to be the digital data. It can provide some applications and display the variations of the activity of the time series in the area. We divide the format into three parts, the data base are display in the shape of point, line and polygon. There are its own coding and data in each spatial object. For example, the traffic network has its own data just like coding, length, speed and so on. These data are written in the table of the data base. When you select the record, the corresponding shape will be selected. In this study, we establish these spatial data which are the topographic chart, the data of traffic network, the block of urban planning, and the flood frequency, and so on to model the evacuation path.

B. Dynamic Evacuation Path

We establish the evacuation path by the data of different time series. We suppose that the depth of the flood get an even rising. So we divide the time into some parts of time series. Upon the data of the time series, we can get the flood frequency in the different time series and help us to make some decision. In this study, we used different decision node in the traffic network and different time series to select the evacuation path like figure3. In figure 3, DP is combined with S1, S2, S3 and S4, and according to the different data bases in each time series these evacuation paths. E is the decision nodes of path.

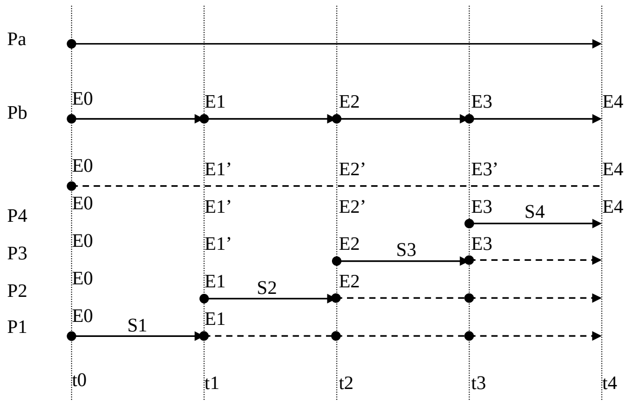


Figure 2. The dynamic evacuation path model

The dynamic evacuation path is defined by

$$DP = \left(P_{s1d1}\right)_{t1} + \left(P_{s2d2}\right)_{t2} + \dots + \left(P_{sndm}\right)_{to}$$

$$DP = \sum_{\substack{t=1\\ d=1\\ s=1}}^{\substack{o\\ m\\ n}} \left(P_{sndm}\right)_{to} \qquad (1)$$

d: the depth of the flood ; t: the time series;
p: the moving path; s: segment of path
DP: Path Distance.

C. Network Analyze

We use Best Route (BR) to calculate the optimum in this study. BR is one kind of the network analysis. It uses the minimum cumulative impedance to find the optimum with two or more traffic nodes in the traffic network. These path nodes can be sequence. And the response unite can be selected in the traffic network data items. For example, we can use the distance and time as the response unites to simulating the more real situation. So we use distance and deliver time to calculate the optimum in this study.

D. Genetic Algorithms

The knowledge representation is the key of whole system of Evacuation Path Model (EPM). There are chromosome, environmental parameters and fitness function. These derived from path table, node table, choose table, dynamic function and GA table in GIS.

1. Code of Chromosome

The concept is developed by initial EP's idea. The result of chosen path could be transformed a serious genes to combine chromosome. Assuming one area has many nodes (for example… P1, P2, P3, …, Pn.), each node has a lot of path to be chosen. The figure 3 shows the node P1 has two paths can be chosen, there are two chosen method. As the same way, the P2 has three chosen method. Thus we can establish the attributes of choose table (like table2) from node table. The table 2 presents the spatial relationship and chosen method of each node.

TABLE 2
CHOOSE TABLE.

Method \ Point	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	….
0	0	0	0	0	0	0	0	0	0	0	0	0	…
1	P4	P1	P2	P1	P4	P5	P6	P10	P8	P8	P16	P4	…
2	P2	P3	P8	P5	P13	P2	P14	P9		P7		P13	…
3		P6		P12	P6	P7	P10	P3		P16			…

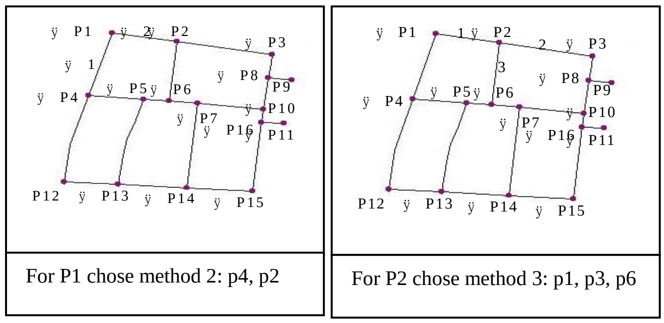


Figure3. The method of node choose

ID	1	2	3	4	5	6	7	8	9
Gene	1	2	3	3	2	0	0	0	0

ID	1	2	3	4	5	6	7	8	9
Gene	2	2	2	1	3	3	1	0	0

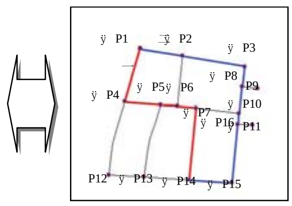


Figure4. The dynamic function to transform the gene code into the EP

The dynamic function is to transform the gene code into the EP (like figure 4). The gene code follows the id to be a chromosome in the GA. The id just the sequence number there is no any means in this table. If we decide the start node is (P1) and the end node is (P14) of EP. The first id just is in the name of start node (P1), the gene code is (1). Then we can choose the next node by index the gene code from choose table. For the start node (P1, 1) we can index P1 choose the (1) method to find out the P4. So the next node is P4, we transform the gene code from (1, 1) to (P1, 1) to (P1, P4). Then repeat the steps above until the next node is just equal the end node. Final we can spatial join table to GIS to draw out the EP (like the red line in figure 4).

The rule of crossover between two chromosomes is before we cut any segment by random, after we crossover them.

Before crossover PathA: 1,1,2,……,3,1 PathB: 1,1,4,……,2
After crossover PathA: 2,1,4,……,2,1 PathB: 2,1,2,……,3

2. Environmental Parameter

DF: Degree of Fitness. The value was calculated by the fitness function. Then it transfers each case's subsistence probability. The function follows:

$$ALIVE_i = DF_i / \sum_{j=1}^{n} DF_j \tag{2}$$

i: the i'th case
j=1 to n, n is the total cases

PN: Population Number. The numbers of total individual, the max living numbers of controlled environment

RR: Reproduction Rate is the copy rate of mother generation. Whether the individual child will be reproduction, it depended on its subsistence probability. If the subsistence probability is higher, it will be more chance copied. It will have more opportunity to evolve.

CR: Crossover Rate is the exchange percentage between any two chromosomes of parents.

MR: Mutation Rate is self-change probability of any chromosome.

3. Fitness Function

The fitness function is the rules to estimate cases and give weight score. It is the tool to judge the better or worse one. It can decide to eliminate the unsuitable case. It including evaluation the rank of EP, the successive nodes of EP, the number of nodes, the length of EP and the number of repeat path in EP choose.

IV. COMPUTING EVACUATION PATH IN SHIJI AREA

This chapter will take the Shiji City in the Keelung River Basin for case in this study. The boundary is like figure 5. We apply river digital topographic map, Digital Elevation Model, Traffic Network Data, Urban Planning Map, etc. According the functions required. We can analyze the demand of data, and build database.

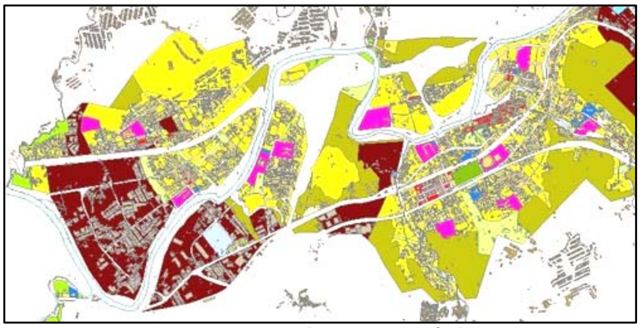
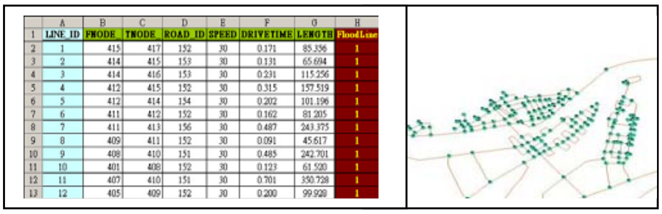


Figure 5. The Region of Shiji

A. Establish the Traffic Street Network

We adopt Taipei Disaster-Prevention Planning for the setting of road class. The roads were classified into four classes: emergency path system (20m) rescue transport path system (15m) fire control path system (8m) and assist path system (8m). To define the boundary of Urban Disaster Prevention & Rescue Refuge Rings, we take the service radius (600m) of high school elementary schools, and the range of refuge rings is about 300m~500m. The walk time of refuge rings is about 5~10 minutes and to consider other resource of Disaster Prevention & Rescue. The construction of the disaster prevention network model is like figure6.



	A	B	C	D	E	F	G	H
1	LINE_ID	FNODE_	TNODE_	ROAD_ID	SPEED	DRIVETIME	LENGTH	FloodLine
2	1	415	417	152	30	0.171	85.356	1
3	2	414	415	153	30	0.131	65.694	1
4	3	414	416	153	30	0.231	115.256	1
5	4	412	415	152	30	0.315	157.519	1
6	5	412	414	154	30	0.202	101.196	1
7	6	411	412	152	30	0.162	81.205	1
8	7	411	413	156	30	0.487	243.375	1
9	8	409	411	152	30	0.091	45.617	1
10	9	408	410	151	30	0.485	242.701	1
11	10	401	408	152	30	0.123	61.520	1
12	11	407	410	151	30	0.701	350.728	1
13	12	405	409	152	30	0.200	99.920	1

Figure 6. Disaster prevention network data establishment

B. Network Analysis of the Evacuation Path

This part we use Best Route to calculate the optimum. We use distance and deliver time to search for the least accumulative cost like figure7 and figure 8. In figure7, BR calculates the least accumulative cost by the distance. But in figure8 is depends on deliver time. There are some different EPs in the tow figure. The reason of the different is the class of the path. The high level paths get the short deliver time, but these cost more distance. So we get the different optimum with BR.

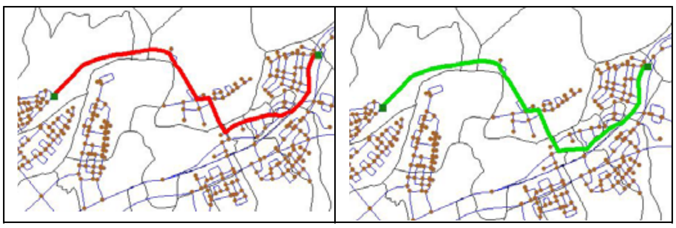


Figure 7, 8. Network Analysis of the Evacuation Path

C. Working Data and Parameter setting

Before process the GA calculation, we must to precede the pattern of Gene Coding. Let the variables indicate the suitable sequence in the computer operating. And we decoding it and return the result (like figure 9).

	A	B	C	D	E	F	G	H	I	J	K
1	Node_ID	PathNum	TNODE1	TNODE2	TNODE3	TNODE4	FloodNode	LINE_ID1	LINE_ID2	LINE_ID3	LINE_ID4
2	1	1	2				1	584	0	0	0
3	2	3	1	10	11		1	584	583	582	0
4	3	1	6				1	581	0	0	0
5	4	1	10				1	580	0	0	0
6	5	1	6				1	579	0	0	0
7	6	3	3	5	8		1	581	579	578	0
8	7	1	8				1	576	0	0	0
9	8	3	6	7	9		1	578	576	574	0
10	9	3	8	12	12		1	574	573	575	0
11	10	4	55	2	4	19	1	571	583	580	572
12	11	3	13	36	2		1	570	577	582	0
13	12	3	9	9	15		1	573	575	569	0
14	13	4	125	21	31	11	1	407	567	568	570
15	14	1	15				1	566	0	0	0
16	15	3	12	14	17		1	569	566	565	0
17	16	1	22				1	564	0	0	0
18	17	3	18	15	20		1	562	565	563	0
19	18	1	17				1	562	0	0	0
20	19	3	25	10	70		1	560	572	561	0
21	20	3	24	17	22		1	558	563	559	0

Figure 9. The refuge node coding

Final we set the parameter like Initial population, crossover rate and mutation rate. After we coding the refuge node, we can create initial population and choose the start node. This study on GA's parameter set up 1500 initial populations, and it has 0.5% crossover rate and 0.1% mutation rate.

To search EP, we use GA technique to get an answer belong to the problem form of the limited type model. The region of answer could be very small. The result could be segment to several areas. It would have low rate to get optimization answer with this model, and the rate of best answer also obvious level down. Generally speak the best answer often appearance on cape area that on the boundary region of the feasible solution. If we only adopt the information of the feasible solution, it would increase search time and difficulty.

Gen (1997) use GA to solve the limited type of problem model, it will often appear the result that not falls into feasible solution region. Gen solve these problems by four kinds of strategy, we use two kinds of methods in the following [6].

1 .Reject Strategy

Once the answer of GA output in not feasible solution region, we throw down that chromosome right away. Make sure the chromosome that making duplicate always in the feasible solution region.

2. Penalty Strategy

At original target function, increase a penalty item. The penalties items will check by the level of individual act against restrict. The degree of act against is more. The penalty function is bigger. Whereas is smaller. These study give different degrees of penalty function with have inundation or not. So we can make the limit question into in limit.

D. Operation Interface and Process

On the process of searching the best evacuation path, we adopt two different methods to find the solution. First, it is on the condition of evacuation path continuous each other and processes the optimization of path. Second, it is on the unlimited condition, so all influential factor proceed in different indicators weights. The first method has better searching speed, the second method has longer time to calculate, but it is flexible. In this study, we take the first method to simulating. The operation interface is like figure 10. The Population Results and Progress Graph like figure 11.

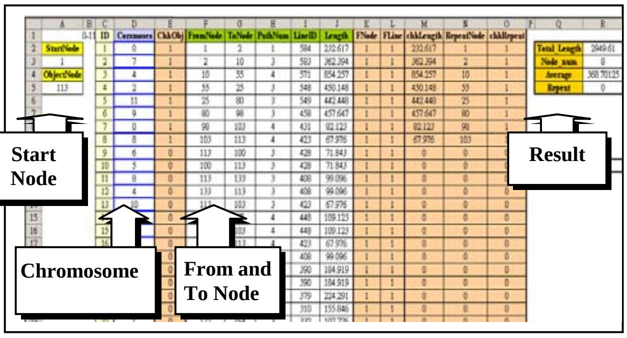
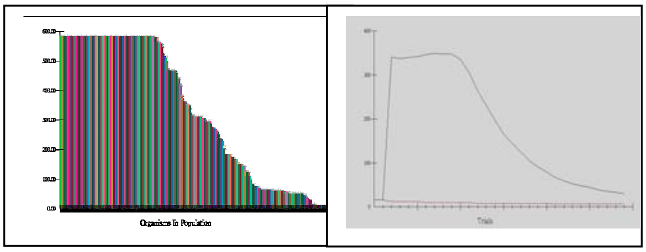


Figure 10. Operation interface

Figure 11. Population Results and Progress Graph



E. The Simulation of the Dynamic Evacuation Path by GA

We calculate the different evacuation path with the data base in the first and sixteen time series by GA. According to the depth of the flood frequency of the time series, GA search for the optimum are distinct like figure 12 and figure 13. In the first time series GA get the smooth EP. In the figure 12 GA calculate the EP with the first time series data, and some data base of the traffic network are unhindered. But in the sixteen time series the data of traffic network get more resistance. So the optimums of EP get a more distance like figure 13.

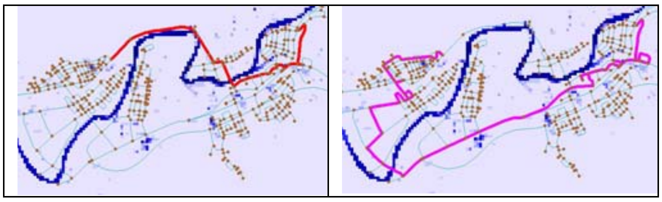


Figure 12, Figure 13. Population Results and Progress Graph

We use the dynamic program to calculate the sequence EPs in different time series. If we set up the more decision nodes, we will get the more real Dynamic Evacuation Path. With the different data base of time series, we divided the time series into three parts. At first, we set up the same destination. We use the data base of the first hour. And it gets the first part of EP like figure 14. Second, we try to set up the traffic node to be the first decision node in the first part of EP. Third, we use the fifth hour data to be the second time series. And calculates the EP from the first decision node and get the second part of EP. Forth like figure 15, we set up the second decision node from the second part of EP, and use the data base of ninth hour to be the third time series. We use GA to calculate the EP from the second decision node and get the second part of EP like figure 16. Finally, we combined with the three parts of EP to be the DEP like figure 17.

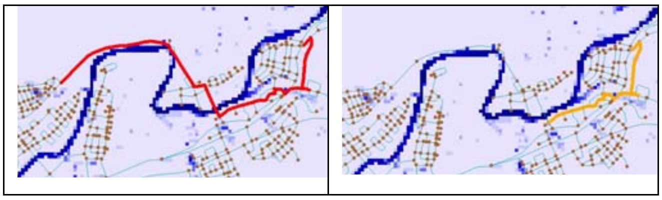


Figure 14, Figure15.The EP of the First Time Series and the Second Time Series

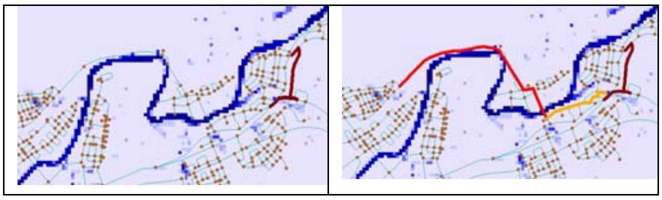


Figure 16, Figure 17 .The EP of the Third Time Series and the DEP of GA

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F. Comparative the EP of NA and GA

In this study we get the different EP by using the NA and GA calculations. The EP of the NA is depending with the least accumulative cost by deliver time. So the simulation of EP choices the fast moving path which is not depends on the least distance. The EP of NA is green color in the figure 18.

The GA searches the optimum by coding, the weight of the data base of the traffic network and penalty function. So the simulation of the GA's EP in some path avoids the depth of flood. The EPs of GA are brown, yellow and red color in the figure 18.

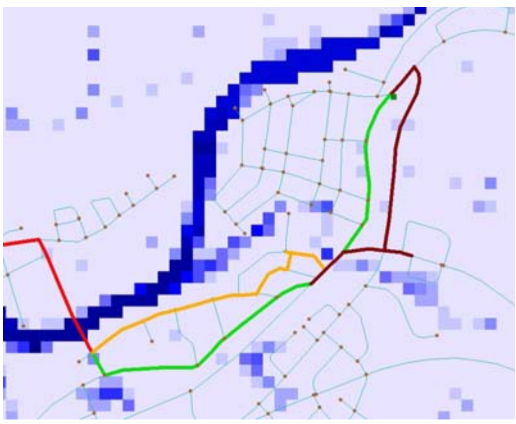

Figure 18.The Comparative the EP of GA and NA

V. Conclusion

In this study, we establish disaster databases to proceed with case study and bring up the preliminary analysis result, Combining GA and GIS to deal with the dynamic time space data, we point on the different selections of the path with the GA and NA, and the simulation can offer the better hermeneutic capability to process dynamic flooding evacuation path modal.

We constructing the database of dynamic time and spatial and the pattern of analyzing evacuation path, and to propose the method of combination further, and analyze the process of the combination of spatial and time information.

Using dynamic program to simulate the evacuation path by calculating with the different time series with these decision nodes which are in the traffic network can provide the more real situation.

NA can set up more suitable data base which are according to the flood data to simulate the more real situation with the time series. With the suitable data NA search the optimum with the least accumulative cost will more flexible.

GA searches the optimum by chromosome operation. The different methods of coding and penalty function may make up the different optimums. So taking a look at the methods is important operation to search the optimum.

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