Transport Safety Management and Cost-Effectiveness Optimization Problem

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abstract: The safety planning should be considered in terms of cost-effectiveness mainly because certain budget constraints usually exist in the real world. The concept of formulation for the problem is discussed with estimation of cost and benefit. The basic concept is to chose the locations which should be improved the road facilities and surface conditions in terms of profitable traffic safety management. The advanced technique should be prepared corresponding to real scale allocation problems. In this study, Genetic Algorithm (GA) is recommended to be applied to obtain the solutions efficiently. The solution given by GA is not exactly the same as the optimum solution. However it works very well to search the approximate value of solution. And also the benefit which is expected from the improvement of the roads system is not given as a proper values because the concept of the benefit of traffic safety itself is often fluctuated. Therefore benefit function cannot be formulated as a linear function . If the problem includes high non-linearity objective function, it is not easy to be solved by conventional techniques. It is revealed that the GA is having the advantages to solve such kinds of problems. Finally the numerical example in Gifu is introduced to show the performance of GA.

1. INTRODUCTION

The number of the fatalities of traffic accidents is one of the indicators which shows the situation of traffic safety in the country. Figure 1 illustrates the change of the number of traffic accidents and safety fatalities in Japan. As the great efforts for traffic safety have been made for many years, the number of accidents had been decreased for 1970's. However the number of fatalities in Japan had started to increase from 1988. Recently it seems to be very difficult to reduce the risk of traffic accidents in Japan. It is always announced that the number of fatalities should be bellow ten thousand for each year. This line is drawn in the Figure as a standard level of accident risk. It can be observed that we have not achieved to this goal. In 1994, there are 729,457 accidents, 881,723 casualties and 10,649 fatalities respectively.

Therefore traffic accident must be great problem in terms of external diseconomy of the road systems. And also roughly speaking, the number of accidents have been increased for these two decades even many countermeasure are proposed. This situation in Japan is often called as the second stage of traffic war by the people who relate with traffic safety research. It is also mentioned that the quality of the accidents had changed. The

advanced countermeasures which correspond to different aspects of the safety problems should be investigated. Thus the traffic safety planning has received increased attention in terms of reduction of danger in driving.
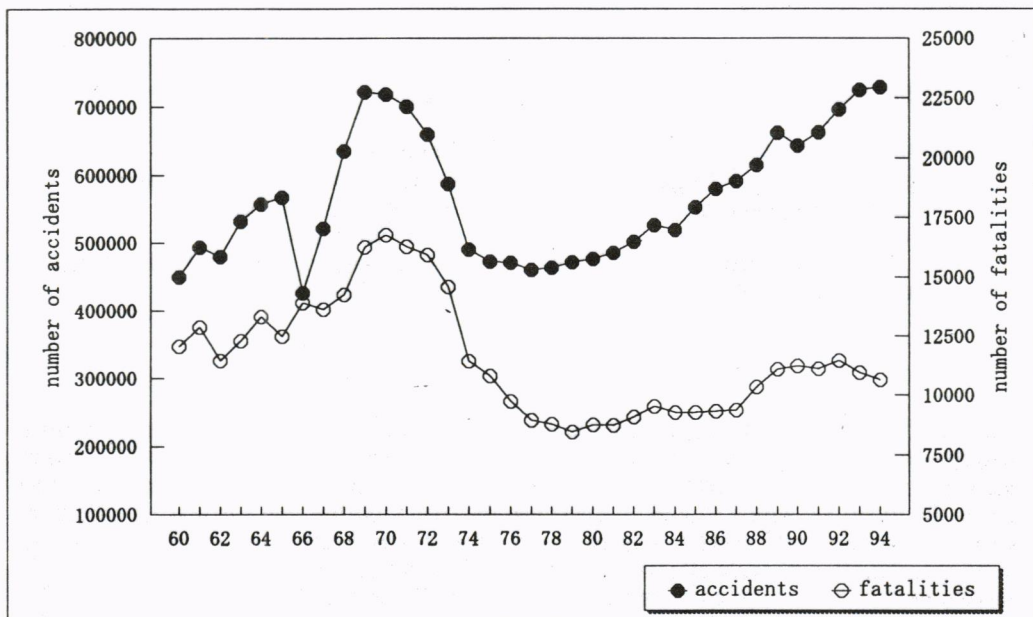

Figure 1 The change of the number of accidents

In the sense of practical applications, the optimization approach using budget constraints is applicable to many problems of infrastructure planning. The searching process of an economic project for traffic safety management can be formulated as a combinational optimization problem. Particularly Integer Programing is one of the typical method for solving the problem. However the real scale problem is usually too large to be solved by mathematical algorithm because of its impracticability of calculation.

Genetic algorithm (GA) are introduced to solve the benefit maximizing problem efficiently in real scale. The GA is one of the computer techniques which is used for searching the solutions of optimizing problem based on the theory of evolution (Akiyama, 1993). The variables in a mathematical programing are described as a chromosome of the individual in GA. If the second highest value of the individual can be found, the combination of genes in its chromosome will indicate a solution of optimization problem.

Even though the estimated value given as a result of GA is not necessarily equal to the optimized value, it may give a good approximation. On the other hand, the search of high second combination can be carried out even in a large scale problem. The empirical result is presented from a case study of the safety planning in Gifu city. It will be known how the genetic algorithm improves the efficiency to obtain the optimal solutions of actual complex traffic safety planning.

2. MATHEMATICAL PROGRAMMING IN TRAFFIC SAFETY PLANNING

The outline of the basic problem considered in the study is mentioned briefly. A traffic safety project for transport networks is assumed to consist of local construction projects whose cost and effectiveness in improving road safety are evaluated in monetary terms. In other words, the optimal combination of local construction projects yields to the

greatest improvement in safety, while remaining within the budget.

The traffic facilities at heavy traffic points on the road networks should be constructed for this purpose. They will have some effectiveness on traffic safety as reduction of accident risk. The cost of constructing each of these facilities and the benefits obtained from reducing the number of accidents are assumed to have been considered in the early planning stages.

The problem arises considering the types and combination of countermeasures that can be carried out within a feasible budget. Therefore the basic concept of optimization problem is described to perform the maximum benefit with the budget constraint as follows (Akiyama and Ohya, 1991) :

$$\max \ TB(x_{ij}) \ = \ \sum_{i=1}^{L}\sum_{j=1}^{N_i} b_{ij}x_{ij} \tag{1}$$

$$subject \ to$$

$$TC(x_{ij}) \ = \ \sum_{i=1}^{L}\sum_{j=1}^{N_i} c_{ij}x_{ij} \ \leq \ Budget \tag{2}$$

$$x_{ij} \ = \ 0 \ or \ 1$$

Let assume the traffic safety project is considered the road network which consist of L routes. And also N_i alternative countermeasures are prepared for each route. The variable x_{ij} indicates the result of selection of the j-th alternative for route i . The value of x_{ij} should be one or zero. If x_{ij} is equal to one, it means that the alternative is involved in the beneficial project. Total benefit $TB(x_{ij})$ in equation (1) indicates the effectiveness of selected countermeasures which are combined corresponding to the value of x_{ij} . Therefore the objective function should be maximized subjected to the budget constraint illustrated in equation (2), where b_{ij} is a benefit coefficient and c_{ij} is a cost coefficient respectively.

Mathematical programming has been recognized as a possibility effective technique for solving this problem. There are useful techniques such as Incremental Benefit-Cost Analysis (IBCA), Dynamic Programming (DP) and Integer Programming (IP) and etc. (National Technical Information Service, 1979). The authors have already summarized these techniques to solve the problems and introduced them to the realistic problem related with Hanshin Expressway safety projects (Akiyama and Shao, et. al., 1991).

Incremental Benefit-Cost Analysis and Dynamic Programming using fuzzy budget constraints to consider the fuzziness in decision making were introduced as well. Each technique has some advantages and particular algorithm implemented in the computer. Although each technique can always give a solution which is mathematically justified, it is difficult to consider the real scale optimization problems. The details of those research would be found in some reports and papers (Akiyama and Uchida, 1988 and Akiyama and Shao, 1993). In this study, the standard algorithm normally used to solve this problem is modified in terms of efficiency of calculating.

A combination of optimal alternatives is produced by mathematical programming. The way to create an algorithm that closely matches reality for practical application is to carefully consider the conditions involved in actual safety planning. In the sense genetic algorithm may provide an efficient and practical method to solve the problem.

3. GENETIC ALGORITHM APPLICATION

The genetic algorithm is recognized as an optimization technique even though it is originally based on the theory of evolution. It can be used to solve the problem of mathematical programing which is formulated previously. The mechanism of a genetic algorithm is summarized in Figure 2. There are many coding techniques to implement the process of genetic algorithm on computer. This variation is related with the detail description of evolution process. Therefore the typical process is mainly mentioned in this study .
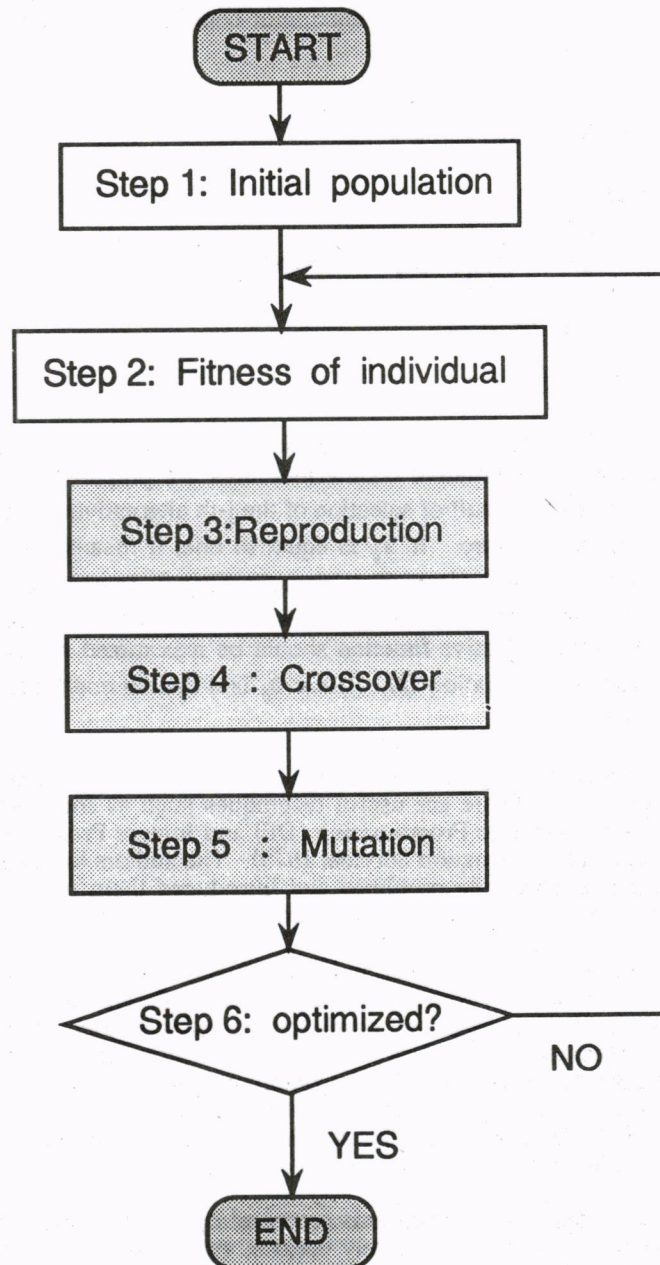

Figure 2 The outline of genetic algorithm

First of all, each individual variable in the original problem should be transformed as a chromosome for evolution. Each chromosome is usually represented by a string which consist of genes depicted as one or zero. Therefore each chromosome is described as follows:

S_1 : 010010001001110111011101101111011010101011111010

S_2 : 111101001000110110010110111101111010101000011110

S_3 : 010010001000000111001010111011100001111000100111

In the step 1, an initial "population" of one chromosome is created. In other words, an initial searching area is defined as a starting point of the algorithm. After each chromosome of individual is defined, the value of fitness can be calculated for each individuals in step 2. The function of fitness is usually described as function f . The value of the function must be some measure of profit, utility, goodness or benefit that we want to maximize. The meaning of fitness may be changed according to the original definition in the problem.

The main operators in genetic algorithm can be seen from step 3 to step 5. Reproduction is a process in which individual strings are copied according to their fitness function value, f . In our example, the fitness function is just the same as total benefit function defined in equation (1). Strings with a higher value have a higher probability of contributing one or more offspring in the next generation. This is an artificial version of natural selection, a Darwinian survival of the fittest among string creatures. In general, the fitness of a chromosome is the probability that the chromosome survives to the next generation (Goldberg, 1989). In the step 3, the following definition of probability is candidated:

$$P_i = \frac{f_i}{\sum_k f_k} \tag{3}$$

where P_i is the probability that individual i survives to the next generation. The use of this formula is referred to as the standard method for reproduction with fitness computation. After reproduction, crossover may proceed as step 4. Basic concept of crossover is to mutate one or more genes in one or more of the current chromosome, producing one new offspring for each chromosome mutated (Winston, 1992). Firstly, members of the newly reproduced strings in the mating pool are mated at random. Secondly, each pair of strings undergoes crossing over as follows: two positions, k_1 and k_2 along the string are selected uniformly at random between 1 and the string length less one.

S_1 : 01001000100111 *11110111011011* 11011010101011111010

S_2 : 11110100100011 *01100101101111* 01111010101000011110

The offsprings for next generation will be produced by the combination of S_1 and S_2. In other words, two new strings are created by swapping all characters between positions k_1 and k_2 inclusively as follows:

S'_1 : 01001000100111 *01100101101111* 11011010101011111010

S'_2 : 11110100100011 *11110111011011* 01111010101000011110

Mutation operator in step 4 is to swap the genes randomly from 0 to 1 or from 1 to 0 for each individual. The two values of probabilities are defined in advance.   The one is the probability of mutation for each individual and the other is the probability of mutation of genes. For example a individual S_3 is selected for mutation by some probability and each gene of the chromosome S_3 is given a chance of changing values. The typical mutation is illustrated as follows:

S_3 : 010010001000█0011100101█011101110000111█000100111

S'_3 : 010010001000█0011100101█011101110000111█000100111

The mutated and offspring chromosomes are added to current population. A new generation is created by keeping the best of the current population's chromosomes, along with other chromosomes selected randomly from the current population. The random selection is iterated according to assessed fitness until the optimized situation appears.

4. PRACTICAL STUDY OF TRAFFIC SAFETY PLANNING IN GIFU

The trunk roads network in Gifu is shown in Figure 3. The sixteen intersections are picked up as typical places of traffic accidents in Gifu according to their frequency. Also they are numbered in the Figure. Some accidents happen at over 80 particular intersections

Figure 3 The intersections of high accidents frequency in Gifu

on the road network every year. Among these intersections, the high risk intersections in which more than 20 accidents happen every year are pointed out. The report of statistics for traffic safety in Gifu City provides the a frequency data of accidents in each intersections. The sixteen intersections are defined as high risk points. They seem to be distributed very widely on the trunk roads. As shown in this Figure, the selected sixteen intersections are located at city centre as well as radical routes to the other cities.

The statistics of accidents are shown in Table 1. Several points with high frequency for fatal accidents can be observed on the national trunk roads such as route 21, route 156 and route 157. Large amount of traffic can be observed in these roads. Therefore these routes tend to have serious accidents involving heavy goods vehicles. Similarly some sites with high frequency for slight accident can be seen on the regional trunk road as route 77 which is a main loop road with heavy traffic.

The proportion of the serious and fatal accidents for these spots cannot be necessarily uniform. This may cause of a lot of factors such as the difference structures of the intersections, the contents of vehicles, surrounding environment and so forth. Therefore it should be memorized that the same countermeasure to the traffic accidents may not give the same effectiveness for every sites.

Table 1 Traffic accidents on each intersection

Site	Route	Slight	Serious & Fatal	Total	Casualties
①	NR 21	65	16	81	24
②	NR 21	41	10	51	14
③	NR 156	45	2	47	3
④	RT 54	36	10	46	16
⑤	NR 157	37	9	46	14
⑥	NR 21	37	8	45	11
⑦	NR 157	41	4	45	5
⑧	PR 151	34	7	41	7
⑨	NR 156	32	7	39	11
⑩	RT 52	30	7	37	10
⑪	CR	30	6	36	8
⑫	PR 197	30	5	35	7
⑬	NR 157	34	1	35	1
⑭	RT 77	22	11	33	12
⑮	RT 77	23	0	23	0
⑯	CR	15	7	22	7

cf: NR:National Road, PR:Prefecture Road
CR:City Road, RT:Regional Trunk Road
Note: Data was taken in 1987

Many types of countermeasure for traffic accidents can be prepared. If some improvement of intersection is considered in terms of traffic safety, physical feature of roads which influence the risk of accidents might be modified (Grime, 1987). After observing the situations of accidents for selected sixteen intersections, an example project is assumed to include five realistic actions for traffic safety improvement. The unit costs for these safety facilities is also assumed to be calculated in early stage of the planning. These values are shown in Table 2.

Table 2 Unit costs for safety facilities

Flashing light	12 / set
Warning sign plate	5 / set
Auxiliary sign plate	5 / set
Road marking	6 /unit
Traffic signals	60 / set

Flashing light is representing the general delineation system which aims at warning the driver approaching the risk of accidents. Next two sign plates are particularly important at the approaches to priority controlled junctions, where drivers may sometimes fail to recognise that they are approaching a junction and therefore fail to stop. And road marking is effected by paint which may be reflectorised by reflecting prisms or by surfaces of contracting colour and texture. Lastly the installation of signals have been a recognised method of controlling traffic and reducing accident at junctions the volume of traffic warrants their use. The installation of these facilities can be observed even in the real situation. For example, the conventional signal equipments are planning to be replaced by the larger sizes in Gifu City. It aims that increased visibility of signals reduces the risk of accidents.

In any cases, the installation cost can be calculated through the unit cost shown in Table 2 . Several facilities are usually installed at the same time because these facilities might work well in such a condition. Therefore each project should includes each installation at certain level then the cost of each project can be accumulated from the unit cost. These values are shown in Table 3.

Table 3 Cost and benefit for each alternative

	Intersection	No.	Cost	Benefit		Intersection	No.	Cost	Benefit
1	Ginan IC	①	320	2,958	25	Kamiijiki	①	462	4,466
2		②	354	1,982	26		②	550	5,088
3		③	184	1,373	27		③	287	1,890
4	Takasagoden	①	135	981	28	Ukaiya	①	265	2,390
5		②	556	5,501	29		②	474	3,049
6		③	59	456	30		③	207	1,810
7	Kitaishiki	①	591	3,310	31	Yotsuya Park	①	219	1,280
8		②	724	6,119	32		②	741	5,609
9		③	231	1,415	33		③	558	4,924
10	Culture Ctr.	①	402	3,435	34	Kinka Bridge	①	363	3,452
11		②	253	2,042	35		②	642	6,082
12		③	494	4,737	36		③	364	2,218
13	Tetsumei-cho	①	438	3,504	37	Chusetsu Bridge	①	219	1,484
14		②	415	2,336	38		②	573	5,125
15		③	350	2,603	39		③	593	4,386
16	Akanabe-hongo	①	460	3,784	40	Kagasima Police	①	462	3,280
17		②	212	1,153	41		②	568	4,461
18		③	76	491	42		③	581	5,591
19	Shingifu St.	①	163	1,404	43	Gifu-Kita Police	①	280	2,730
20		②	537	5,005	44		②	76	617
21		③	543	4,616	45		③	230	1,631
22	Wakamiya-cho	①	271	2,304	46	Nagamori-honmachi	①	283	2,561
23		②	490	4,510	47		②	227	1,462
24		③	595	4,731	48		③	668	6,052

In the same manner the benefit can be calculated as measures of the effectiveness of alternatives. If the effectiveness is counted in monetary term, it is usually based on accident costs which is defined as compensation of accidents (e.g. Dalvi,1988) . Benefits of alternatives are also shown in Table 3 as numerical examples.

As mentioned before, the sixteen intersections in Gifu are picked up to show an numerical example. It is assumed that three alternatives for each sites can be prepared. They are independently feasible each other. That means that forty eight (= 3 times 16) alternatives are proposed as feasible solutions overall the road networks. Even though every alternative have been proposed through the particular consideration, some of them must be selected because of budget constraint. This situation can be observed in the real field of traffic safety planning. Even if the effectiveness of countermeasures are large enough, the total cost cannot be exceed to the annual budget for traffic safety project. Therefore it is reasonable that a subset of all countermeasures can be realized in each fiscal year.
Looking back to our formulation shown in equations (1) and (2), the most profitable combination of countermeasures may be acceptable in planning. In another sense, some alternatives from 48 must be selected to establish the best combination in the safety project.

It is possible to try every combination, but the number of options is incredibly huge in this problem. The number of combination is mathematically counted as $2^{48} = 281.4749 \times 10^{12}$. It is obvious that the brute-force testing is impracticable. Actually the authors have tried to know how wasteful the search for all combination is. Even though the coding of the searching algorithm is very simple, it seemed to waste calculating time. After the one day and half computing, about a third cases were checked but the calculation was quieted because of its impracticability. The solution which appeared at half way of this tired iteration gives cost and benefit as 7,854 and 64,755 yen respectively. That means that the optimal solution could not be given through the conventional technique.

The genetic algorithm is introduced to give a approximation. As the strings of gene in the algorithm represent acceptance or rejection for each alternatives, the length of each string is equal to 48 for this calculation. The four parameters should be given at the initial step of the algorithm. The abbreviations, PO, SR, RE and RM. indicate population, selection rate, crossover rate and mutation rate respectively. These parameters are usually determined by try and error. Five different sets of the parameters are prepared. And also three cases which have the different budget constraint between 8000 and 10,000 $\times 10^4$ yen are assumed. New population is created according to accessed values for individuals. In this algorithm the value of benefit is used as fitness values. If an unfeasible solution is found, the value of the fitness is changed to zero automatically.

The calculation results of genetic algorithm are shown in Table 4. The highest scored individual with its total cost and benefit is memorized in each generation. The calculation is continued to 3,000 generations and the solution which gives the highest benefit is illustrated in this Table.

Even the optimal solution cannot be given, approximate values of maximum benefit may be known for each budget constraints. For example, total benefit with budget as 8,000 $\times$ 10^4 yen is about $73,000 \times 10^4$ yen because the solutions seem to be in stable and the maximum value of benefit among five cases is 73,059 for the this solution. It is also known that the algorithm finds much better solutions with higher value of benefit comparing to the result of the previous trial. This tendency for solutions may be preserved in the cases of other budget constraints. Even though they are all approximate value of optimal solution, it is easy to imagine that the total benefit is estimated as about 81,000 and 90,000 for other cases with two different constraints.

The content of each solution is investigated to know the detail characteristics of the proposed safety projects. However, effective countermeasures which are commonly

## Table 4 The results of calculation by genetic algorithm

Budget constraints	GA parameters (PO, RS, RC, RM)	Solutions	Total cost	Total benefit
8000	30, 0. 5, 0. 8, 0. 3	1010110000000001001101101100000001100100011110111	7, 993	72, 024
	30, 0. 6, 0. 7, 0. 2	1000100001010001001101101101000011000100011000101	7, 956	73, 059
	30, 0. 7, 0. 4, 0. 2	0010100000010001011111101100010011100100001100000	7, 990	72, 993
	40, 0. 4, 0. 6, 0. 5	0010110010111000001000101011010011100100111111000	7, 960	70, 111
	40, 0. 5, 0. 7, 0. 3	1000100000011000001111001101010001100010001100101	7, 896	71, 679
9000	30, 0. 5, 0. 8, 0. 3	1010110000011011001101101110010001100100011110101	8, 974	80, 645
	30, 0. 6, 0. 7, 0. 2	0001100101110001010101101101010011100000011000001	8, 974	81, 494
	30, 0. 7, 0. 4, 0. 2	1000110100010000001101111100000011100100001110101	8, 925	81, 455
	40, 0. 4, 0. 6, 0. 5	1011010011110100010111101110010001100100001100101	8, 986	78, 548
	40, 0. 5, 0. 7, 0. 3	1001110000011000001111101110010011100100001010101	8, 956	79, 937
10000	30, 0. 5, 0. 8, 0. 3	1010100100110001011101101100000011011010101110101	9, 925	88, 722
	30, 0. 6, 0. 7, 0. 2	1011100001110001001101101101010011001100110010 1	9, 970	89, 733
	30, 0. 7, 0. 4, 0. 2	0010100101011000011101101101010011100100001101101	9, 997	90, 285
	40, 0. 4, 0. 6, 0. 5	1010100100000001000111011101010111100101001 11001	9, 947	86, 689
	40, 0. 5, 0. 7, 0. 3	1001100000111001000100111011010011100100011110111	9, 998	88, 408

(×10, 000yen)

cf: PO:population,   RS:rate of selection,   RC:rate of crossover,   RM:rate of mutation

involved in solutions can be revealed. The variables, x_5, x_{12}, x_{25}, x_{34}, x_{35}, x_{42}, x_{43} and x_{48} are tend to be selected when the total benefit becomes higher in any budget constraints. These alternative may be profitably designed and recommendable for the safety projects.

The convergence of the solution is also investigated to consider the stability of the algorithm. The results with highest benefit for each budget constraint are presented in Figure 4.
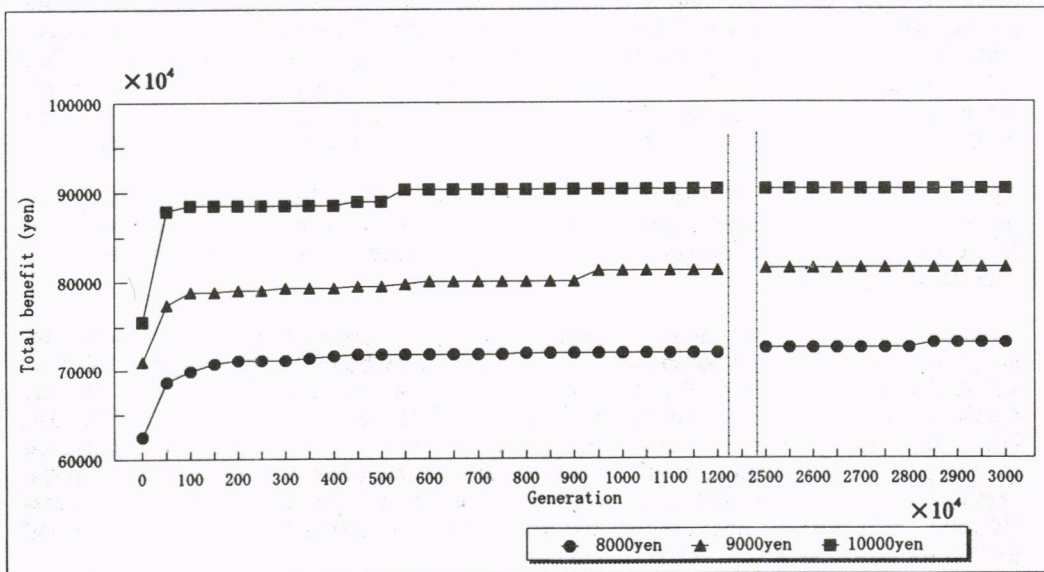
Figure 4 Convergence for best-of-generation for each case

In this figure convergence seems to be almost terminated in less than 1,000 generations. The solutions might be in local maximization area. However they can give the profitable combination of alternatives in traffic safety project because of this stability.

The population used here is thirty or forty for each generation. The three thousand generation seems to indicate a great deal of search. However it is just about 4.2×10^{-8} percent of all combinations (as mentioned it is 2^{48}). The efficiency of convergence relates with population (PO) and reproduction probability (RS). In these examples it can be said that the parameters as (PO, RS) = (30, 0.7) are significant to obtain better solutions in any constraints. And also mutation probability (RM) may be maintained in low value as 0.2 or 0.3 to search the good solution. Otherwise the algorithm becomes similar to random search. The fourth examples in each constraints in Table 4 which has the value of RM as 0.5 produce the lowest values of benefit. This may connected with the randomness of search and the efficiency of convergence.

5. CONCLUDING REMARKS

This study tried to prove that genetic algorithms can be useful for traffic safety planning in place of the conventional mathematical programming. Even though genetic algorithm gives only approximate solution of the problem, the great progress have made to solve the real scale traffic safety planning in terms of efficiency of calculation.

If the monetary expression is used for the effectiveness of accident countermeasures, the mathematical formulation is easy to be established. However, the costs and benefits of traffic safety projects cannot be properly determined before the optimization. It indicates that too much precise information is not necessarily important to make decisions. In this sense the conventional mathematical programing may not be applicable to the real scale allocation problem.

Practical method for making the safety project is proposed. The solutions provided by genetic algorithm may not be an optimal solution. However it is able to find a reasonable solution of the problem in the sea of huge number of combinations. It is confirmed at least that genetic algorithm gives good performance to obtain an acceptable and practical solution instantly. The numerical examples are presented as improvement projects of intersections in Gifu. The sixteen sites are picked up but they are not enough to cover the serious risk on the road networks. Therefore genetic algorithm itself should be modified based on the related technical research.

Further discussion would be recommended to extend the study because there are some other important aspects in road safety planning.

Firstly the technique of genetic algorithm cannot be completed to be applied to practical problems. The simple and popular coding way of GA program is introduced in the paper. However the determination of the probabilities such as RS, RC and RM must be important to find the proper direction to optimal solution. And the techniques of crossover is said to be important to increase the efficiency of searching. The many research results in related field will be useful to modify the algorithm for considering real size optimization problem.

Secondly, the installation of equipments may effect to reduce the number of accident on a particular site. It looks a very simple phenomena. If the shift of accident risk is taken into account, the problem becomes much complicated. Reduction of the risk for one site sometimes increases the risk of other sites because the pattern of traffic flow on the networks might be changed according to the situation. This phenomena are often observed when the real project have done on the large trunk road networks. The authors are now trying to build up the model which has the optimization approach for traffic safety planning considering the traffic flow on the network. The hybrid model between the

maximization technique by GA and traffic assignment techniques with link interaction might be very powerful to solve the problems.

In addition, the results of these calculations can aid in making better informed decisions. They can help by taking into account more of the real world factors that inevitably affect the implementation and final success of the safety projects that are made.

ACKNOWLEDGMENTS

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