APPLICATION OF GENETIC ALGORITHMS MODEL FOR ROAD INVESTMENT OF RESTORATION PLANNING

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Abstract: Realization of a systematic restoration process at the time of a disaster is an important issue for the speedy recovery of road networks. When choosing a systematic restoration strategy, however, both the combination of restoration groups for cooperation and the priority order of restoration works must be decided simultaneously and it is difficult to find an optimum combination of these two matters. In this study, the Genetic Algorithm was used to establish a restoration scheduling model taking into account the cooperation system of restoration groups. The established model will be used for solving restoration problems at the national highway level. To allow efficient searches for optimal solutions, this study made it possible to establish a systematic restoration schedule by incorporating newly devised cording method in the process of GAs. As a case study, optimized calculation of a cooperative restoration schedule was conducted for a road network in southwestern Hokkaido.

1.INTRODUCTION

The Hanshin-Awaji Earthquake caused tremendous damage and became a turning point in Japan's disaster-control administration. It was taken as an opportunity to review the nation's basic disaster-control plan, and measures to prevent accident damage were added as part of the plan. For quick restoration from damage, it is essential for related organizations to exchange information and work in cooperation with each other. There are actually some arguments about the legalization of CALS for disaster prevention and wide-area support agreements among local governments.

In the field of traffic engineering, research on disaster prevention and the restoration of road networks is divided into research on pre-disaster measures and post-disaster measures. In this study, research was conducted from the latter point of view. Research on the post-disaster restoration process has mainly focused on the restoration of traffic and lifeline networks.

Six key words for research on restoration processes are as follows: (1) priority order of restoration in damaged links, (2) allocating of machinery and materials, (3) assigning restoration groups, (4) hierarchy of network, (5) isolated area and (6) cooperation among restoration groups. Among these key words, no research has been conducted on (6). This is partly due to the problem of the combination of various conditions for the "cooperation system," since the constrained combination of restoration groups, priority order of the restoration of damaged links and other matters have to be taken into consideration at the same time. For example, when deciding the priority order of restoration of N damaged links, the number of priority combinations of restoration is N!. If the assignment of restoration groups for damaged links is also considered, the number of combinations becomes enormous, and making it difficult to find the optimized restoration strategy.

In this study, coding that would structurally satisfy the constrained combinations of restoration groups was conducted on gene strings in order to apply GA to constrained scheduling problems, such as the cooperative restoration problem, and a method of conducting crossing and mutation processes to save the coding was suggested. This made it possible to apply GA to a scheduling problem of assigning one construction work simultaneously to each group.

In this paper, In Chapter 2, specific contrivances used in coding genetic strings and crossing/mutation processes are presented. In Chapter 3, a cooperative restoration model is developed by referring to the "Hokkaido Nansei Oki Earthquake Okushiri Island Damage Restoration Promotion and Liaison Council," which was an actual cooperation organizing committee. In Chapter 4, calculation is conducted by applying the established model to the national highway network in southwestern Hokkaido as a case study. The conclusion of this study is presented in Chapter 5.

2. APPLICATION OF A GA TO A COOPERRATIVE RESTORATION PROBLEM

For the cooperative restoration problem in this study, an attempt will be made to find an effective restoration schedule by allocating N damaged links Li (i = 1 - N) in a road network after a disaster to M restoration groups Rj (j = 1 - M). Rj may cooperate with each other and Li may be allocated to multiple Rj simultaneously. However, there is a minimum required restoration ability and amount of materials for restoration of each damaged link, and only the combination of restoration groups with certain restoration abilities and amounts of materials can undertake the restoration of the damaged link. The following problem can be established by assuming RTi, which is an aggregate combination of Rj, for each Li.

●Objective function: OBJ→Min
●Subject to: Restoration combination for each damaged link Li

$$RTi \in F$$

F : All aggregate combinations of Rj (j = 1 - M) (2^M combinations possible)
RTi : a subset of F for which Li can be allocated
●Design variable of TSP-type string component

$$YTi (i=1 \sim N)$$

●Candidate design variable of decimal coding component

$$YBik \in RTi \in F, \quad (k \in 2^M) \qquad (1)$$

Starting in the next section, contrivances used for coding, crossover and mutation will be explained.

2.1 Representation of Cooperative Restoration Schedule by Genetic Strings

To represent cooperative restoration schedules by genetic strings, two different types of information are represented by gene strings: (1) the order in which the damaged links will be restored and (2) which group a restoration group will cooperate with to undertake restoration of the allocated damaged link. The types of information which must be included in the genetic string are the order of works in damaged link Li and the allocation of the damaged link Li to restoration groups Rj. In this study, TSP-type and decimal coding methods are described and represented on one genetic string simultaneously. In this case, the design variable in the TSP-type coding section represents the damaged link Li, and the restoration priority is higher for genetic loci on the left side. The design variable in the decimal coding section represents the cooperation combination of restoration groups Rj. The length of the genetic string is N×2 to represent each type of information in real numbers. When the design variable in the TSP-type coding section is YTi (i = 1 to N) and the design variable in the decimal coding section against YTi is YBik ($i = 1 \sim N$, $k \in 2^M$), the genetic strings are configured as shown in Figure 1.

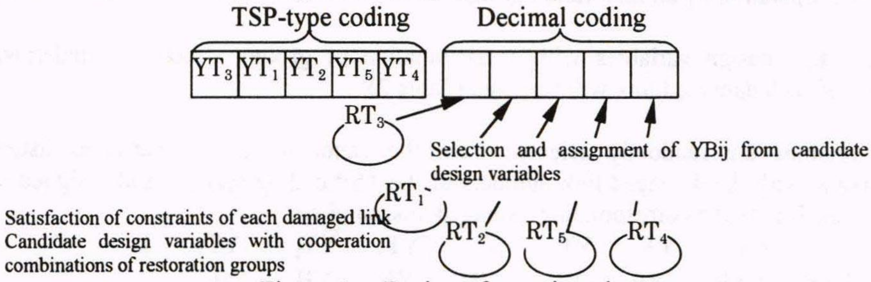

Figure 1. Design of genetic strings

As a example, explanation will be given regarding a case where seven damaged links are allocated to four restoration groups. First, the first half of the genetic string is coded using the TSP-type coding method. In this part, the link numbers are placed from the left side without overlapping each other in order of priority for the restoration of the links.

■TSP type [YT_1 YT_4 YT_2 YT_6 YT_7 YT_3 YT_5]

Table 1. Design variables representing the cooperation systems of all groups (in the case of four groups)

Design variable	Cooperation group	Design variable	Cooperation group
1	Group 1	9	Groups 2 and 4
2	Group 2	10	Groups 3 and 4
3	Group 3	11	Groups 1, 2 and 3
4	Group 4	12	Groups 1, 2 and 4
5	Group 1 and 2	13	Groups 1, 3 and 4
6	Groups 1 and 3	14	Groups 2, 3 and 4
7	Groups 1 and 4	15	Groups 1, 2, 3 and 4
8	Groups 2 and 3	16	Groups 1, 2, 3 and 4

Table 2. Candidate design variable for each damaged link

Damaged link no.	Design variable	Combination of restoration groups in charge
1	10	Groups 3 and 4
	14	Groups 2, 3 and 4
2	11	Groups 1, 2 and 3
	12	Groups 1, 2 and 4
3	6	Groups 1 and 3
	13	Groups 1, 2 and 3
•	•	•
7	9	Groups 2 and 4
	13	Groups 1, 3 and 4
	14	Groups 2, 3 and 4

For the latter half of the genetic string, decimai coding is applied. In this case, established design variables contain information on a cooperation system in which multiple groups can be in charge of one damaged link simultaneously (Table1). The cooperation system is handled by setting design variables with information about multiple groups which take charge of one damaged link at the same time. By including the cases in which no groups participate in restoration and setting the numbers from 1 to 2^M as design variables, all combination patterns in the cases up to M groups cooperated can be described. Table1 shows all sets of combinations when there are four restoration groups as design variables that represent cooperation systems. Since it is impossible that all groups do not participate in restoration, the information contained in the design variable 16 (information of the cooperation of all four groups) is regarded as a dummy and used as information in the case of cooperation by all restoration groups.

Next, candidate design variables with a combination of groups which can undertake restoration of each damaged link will be listed (Table 2).

Design variables are randomly selected from the candidate design variables listed, corresponding with the damaged link numbers of the TSP coding section, and assigned to the same gene loci as the corresponding damaged link numbers.

■TSP type [YT_1 YT_4 YT_2 YT_6 YT_7 YT_3 YT_5]

■Decimal type [$YB_{1,14}$ $YB_{4,1}$ $YB_{2,12}$ $YB_{6,3}$ $YB_{7,5}$ $YB_{3,6}$ $YB_{5,8}$]

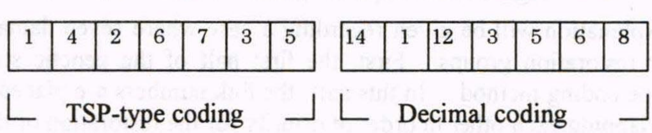

Figure 2. Prepared genetic strings

Table 3. Allocation of damaged links to restoration groups and their order Group

group	Link numbers to be restored and their order Link number
1	④→ ②→ ⑦ → ③
2	①→ ② → ⑦ → ⑤
3	①→ ⑥ → ③ → ⑤
4	①→ ②

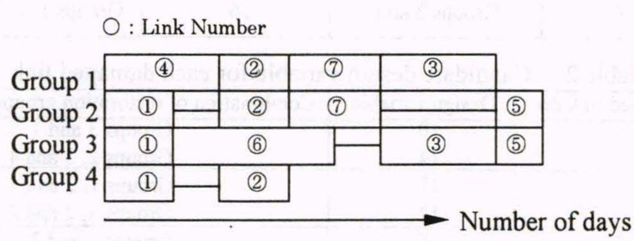

Figure 3. Decoded restoration schedule

Using the above operation, the design variables are positioned in each coding section and the genetic strings shown in Figure 2 were configured.

With the information on the restoration link numbers and priority order in the first half of the string and the design variables representing the cooperation in the latter half of the string, the genetic string can be converted into a cooperative restoration schedule. Figure 3 shows the restoration schedule when the genetic string shown in Figure 2 was converted using the information in Table 3.

2.2 Crossover and Mutation for Restriction of Design Values Combination

In this study, the cooperative restoration schedule is represented by using different coding methods in one gene string. In past studies, crossover was conducted individually using the crossover method corresponding to each coding section. However, if a completely random crossover is simply conducted in each coding section in the case of the genetic string configuration in this study, the combination constraints of the restoration groups in charge are broken and combinations with which restoration is impossible (missing genes) are generated. It is therefore necessary to find a crossover method in order not to destroy information on candidate design variables.

In this study, the design variables which represent the "damaged links" and the design variables which represent the "cooperation systems" in the genetic strings in TSP-type and decimal coding methods are treated in the crossover process together by linking their gene loci with each other. The idea is to use different types of information constituting the restoration schedule, "damaged link number" and "group in charge of the link," as one block (Figure 4). This prevents the generation of combinations of restoration groups which do not satisfy constrained conditions in the solution search process of the GA.

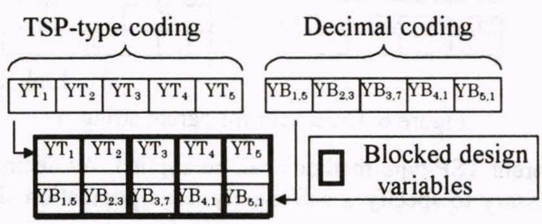

Figure 4. Blocking of design variables

By using the above concept, crossover is carried out in the following manner:

1) The TSP-type and decimal coding sections of the selected parent gene string are blocked and disconnected at the corresponding gene loci (Figure 5).

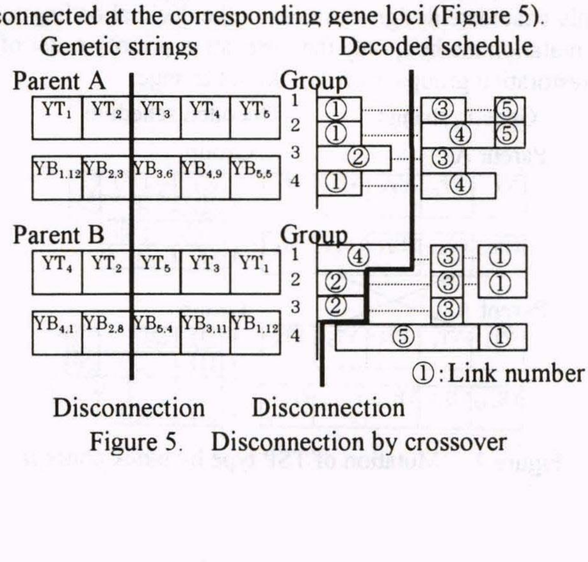

Figure 5. Disconnection by crossover

2) In the same way as in the TSP-type crossover method, the blocked TSP-type design variables of the parent string B are replaced in the parent string A without changing the priority order so that the variables do not overlap with the TSP-type design variables of the parent string A.

Explanation will be given about the parent string A (Figure 6). The design variables of parent A (YT) are placed in order of [1, 2, 3, 4, 5] and disconnected to [1, 2] and [3, 4, 5]. The design variables of parent B (YT) are placed in the order of [4, 2, 5, 3, 1]. Here, the design variables of parent A, YT [3, 4, 5], are replaced. The equivalent design variables of parent B (YT) are placed in the order of [4, *, 5, 3, *], and these are replaced with the design variables [3, 4, 5] without changing this order. As a result the order of YT of parent string A becomes [1, 2, 4, 5, 3] and the design variables YB are also replaced together with their corresponding YT.

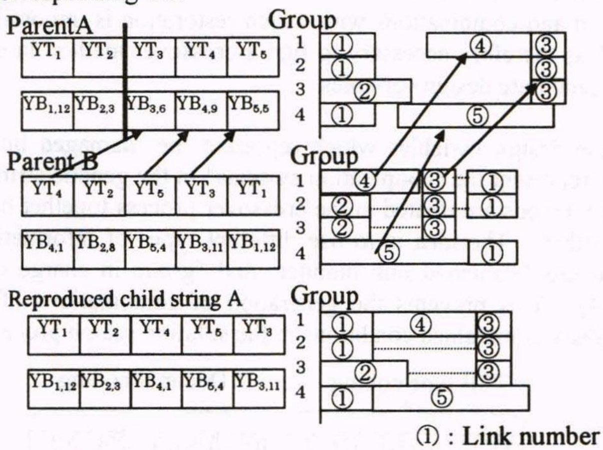

Figure 6. Crossover for parent string A

For crossover, different TSP-type methods can be applied. As decimal coding is applied, however, it is necessary to specify a sufficiently large population size due to the reason stability of result.

Two methods were used for the mutation process (Figure7, Figure8). One was a method of TSP-type mutation in blocks. The other was a method of choosing design variables randomly from only candidate design variables in the decimal coding section and replacing them. In the first mutation method, only the restoration priority order of damaged links are replaced and the restoration groups in charge do not change.

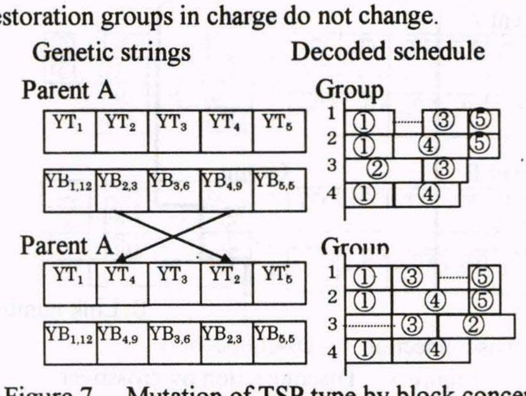

Figure 7. Mutation of TSP type by block concept

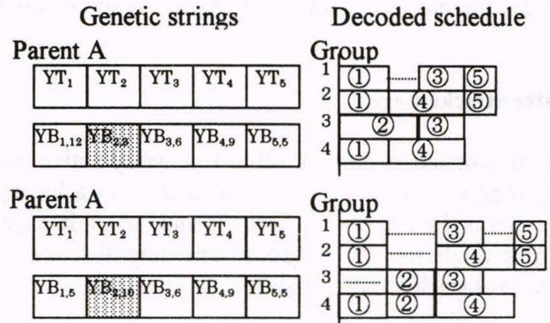

Figure 8. Mutation of only the information on cooperation systems

As in the case of crossover, TSP-type mutation is used for blocks. In the second method, the restoration priority of damaged links does not change, but the cooperation system of the restoration groups in charge does.

3. MODELING OF A COOPERATIVE RESTORATION PROBLEM

In this chapter, a model is developed for the cooperative restoration problem. Calculation methods are established regarding the number of days required for restoration of damaged links, queuing time and objective functions, which are necessary for the establishment and evaluation of the schedule. In the next chapter, a GA is applied to the established model by incorporating the ideas suggested in this study and a case study is conducted using an actual network.

3.1 Modeling of a Cooperative Restoration Problem

The Hokkaido Nansei Oki Earthquake Okushiri Island Damage Restoration Promotion and Liaison Council is an example of systematic cooperation in post-disaster restoration works. Activities of this council included examination of environmental measures for implementation of projects, information exchanges about materials and equipment charges and measures to secure them, and the understanding and coordination of planned project details. The council presented the Liaison record of the project implementation schedule (Table4) below to related organizations, restoration contractors and the Construction Association to forecast the supply and demand for restoration. By understanding the number of machines, materials and workers available from each organization, combinations and periods of work were adjusted to conduct restoration of damaged sections which could not be covered by a single restoration group.

Table 4. Liaison record of the project implementation schedule

Name of project	
Organization implementing the project	
Place of implementation	
Period of construction machinery use Period of construction material use Period for which workforce is necessary	(Year) (Month) - (Year) (Month)

From the above example, it can be said that the cooperation among restoration groups means the restoration of damaged sections which cannot be restored by a single restoration group, by flexible use of the available workforce, construction machinery and restoration materials. In this study, therefore, the frame of the cooperative restoration problems is defined as follows:

1) Condition of disaster stricken area

There are two types of damage condition subject to cooperative restoration. One is damage to a wide-area road network beyond the jurisdiction of a local government due to natural disasters. The other is the condition where the amount of damage to a damaged link exceeds the capacity of a single restoration group. The time distance to a damaged link is longer than normal due to obstacles and bypasses.

2) Restoration groups

Each restoration group has restoration capacity. Each group also has its base and territorial node for which it is in charge. If the node of one of the damaged links is its node, the group can undertake the restoration. The territory of a restoration group can overlap with territories of other groups, and multiple groups can cooperate to restore damaged links in overlapping territories (Figure 9).

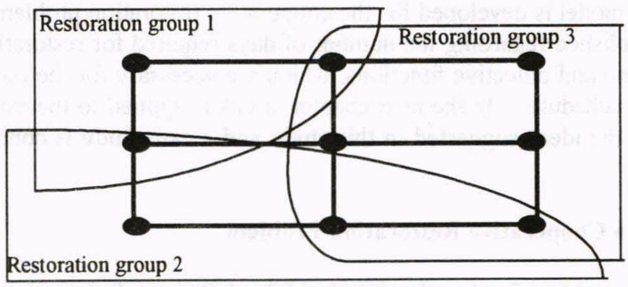

Figure.9 Conceptual diagram of the territories of restoration groups

Each restoration group also has its own personnel, construction machinery and materials. The restoration capacity of a group at the time of cooperation is calculated by Eq.2. Some combinations of restoration groups may be effective as surplus construction machines can be used by more workers. The restoration capacity is represented by the amount of damage (unit) that can be treated in one day (unit/day).

$$SURAi = \mathrm{Min}\left(\sum_{j \in CTi} HPi,j / \alpha ,\ \sum_{j \in CTi} MPi,j \right) \times \beta \qquad (2)$$

N: Number of damaged links
M: Number of restoration groups
SURAI i (i = 1 - N): Capacity of a restoration group participating in the restoration of damaged link i at the time of cooperation (unit/day)
CTi (i = 1 - N): Aggregation of groups j participating in the restoration of damaged link i
HPi, j (i = 1 - N, j = 1 - M): Number of members of a group participating in the restoration of damaged link i
MPi, j (i = 1 - N, j = 1 - M): Number of construction machines of a group participating in the restoration of damaged link i
MAi, j (i = 1 - N, j = 1 - M): Number of restoration materials of a group participating in the restoration of damaged link i
a: Number of workers handling construction machinery per day
(3 in this study, assuming three shifts a day.)
b: Restoration capacity per construction machinery (unit/day) (1 in this study)

3) Time Required for the Restoration of Damaged Links

In this study, it is assumed that the number of days required for the restoration of each link can be calculated by dividing the amount of damage to the damaged link by the total capacity of the group in charge of restoration. However, when the number of workers, construction machines or materials of the group in charge is smaller than the minimum required number, it is assumed that the damaged link cannot be restored. It is also presumed that restoration efficiency cannot be improved if the restoration capacity of a certain value or greater is concentrated on one damaged link. Thus such a value is designated as the saturation restoration capacity for each damaged link. Restoration is possible only when the cooperating groups can satisfy the minimum required amount of materials and total restoration capacity. These relationships are presented as follows:

When either $MNHPi > \sum_{j \in CTi} HPi,j$, $MNMPi > \sum_{j \in CTi} MPi,j$ or $MNMAi > \sum_{j \in CTi} MAi,j$ is satisfied,

$$NRDi = \infty \text{ (a significantly large number in calculation)} \qquad (3)$$

If Eq. (3).is not satisfied,

When $SURAi < RSPi$

$$NRDi = SAi / SURAi \qquad (4)$$

When $SURAi \geqq RSPi$

$$NRDi = SAi / RSPi \qquad (5)$$

SAi (i = 1 - N) : Amount of damage in damaged link i (unit)
RSPi (i = 1 - N) : Saturation restoration capacity of damaged link i (unit/day)
SURAi (i = 1 - N): Total restoration capacity of multiple restoration groups in charge of damaged link i (unit/day)
MNHPi (i = 1 - N) : Minimum number of workers required for the restoration of damaged link i
MNMPi (i = 1 - N): Minimum number of construction machines required for the restoration of damaged link i
MNMAi (i = 1 - N) : Minimum amount of materials required for the restoration of damaged link i (unit)
NRDi (i = 1 - N) : Number of days required for the restoration of damaged link i

From the conditions above, the number of days required for restoration is calculated (Figure10).

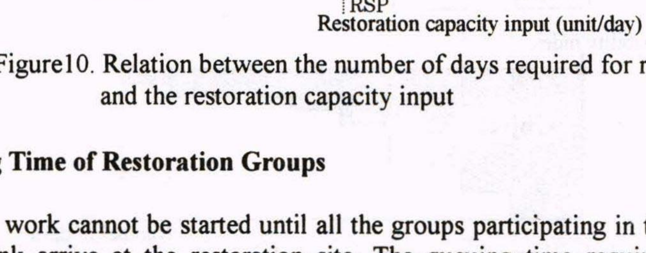

Figure10. Relation between the number of days required for restoration and the restoration capacity input

4) Queuing Time of Restoration Groups

Restoration work cannot be started until all the groups participating in the restoration of a damaged link arrive at the restoration site. The queuing time required before starting restoration is calculated by Eq. (6).

$$SMTi = Max(MTi,j) / 24 \quad (j \in CTi) \tag{6}$$

SMTi (i = 1 - N): Queuing time required before beginning the restoration of damaged link i (day)
CTi (i = 1 - N): Aggregation of groups j participating in the restoration of damaged link i
MTIi, j (i = 1 - N, j = 1 - M): Shortest time distance from the base of group j to damaged link i (hour)

In this research, the queuing time of the restoration groups was ignored if it was shorter than one day.

The above is the basic framework of a cooperative restoration problem. The combination of groups with which restoration of each damaged link becomes possible is incorporated into the gene string as a design variable.

3.2 Setting Objective Functions

Typical objective functions in an optimized restoration problem of a road network include (1) days of restoration and (2) cumulative unrestored degree 1). Restoration of networks of the scale and damage condition presented in this study takes several months to a year. Therefore, objective functions are established from the viewpoint of cumulative unrestored degrees rather than by simply making the days of restoration as few as possible. Also, use of the importance of links, which is the concept of service level unique to each link, was avoided in this research. This must be done to quantify the entire network when the damaged links are restored and evaluate the restoration schedule for the entire recovery process of the network, since the shortest time distance between nodes and other conditions change easily according to the order of the restoration works.

In the links constituting the target network, time distance is greater at the start of restoration due to the damage, and the time distance performance of the entire network gradually returns to a normal state. Therefore, based on the produced restoration schedule, the OD accessibility index [15] is calculated using the network's time distance which was recovered at each stage of the restoration of the links. Then the cumulative value of the increase in the index by the recovery of the time distance of links after restoration and the time to complete restoration of damaged links is used as the objective function for minimization(Figure11).

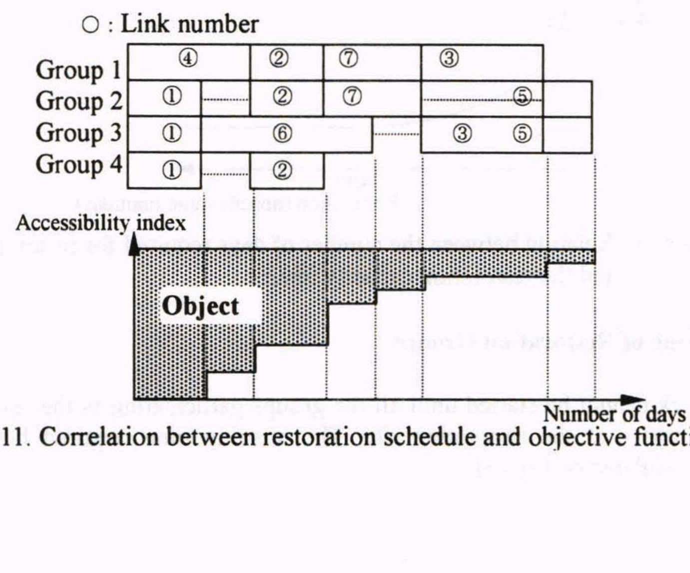

Figure 11. Correlation between restoration schedule and objective function values

$$OBJ = \sum_{i \in N} \{(Si - S'i) \times RTi\} \tag{7}$$

N : Aggregation of all damaged links
Si : Accessibility index after the restoration of damaged link i
S'i : Accessibility index before the restoration of damaged link i
Rti : Time required to complete the restoration of damaged link i

4. CASE STUDY

In this study, it was assumed that multiple links of a national highway network including prefectural roads in South-Western Hokkaido had been damaged simultaneously due to a natural disaster, and calculation was conducted using a model established in this study.

4.1 Setting Damage Conditions

The time distance between nodes at the time of disaster was assumed to be greater than that at a normal time. In this case, an appropriate value which was larger than that of a normal time was given, on the assumption that there were some parts where the damaged links were cut off in coastal areas although there are some bypasses in flat areas. These time distances were established based on the results of past hearing surveys and the records of damage. The OD used was based on the national road traffic survey of 1990. Table 5 shows the data on damaged links.

Bases and territories for 10 restoration groups were established. Table 6 shows the data on the restoration groups, and Figure.12 shows the location of target network and damaged links and the territories of restoration groups. Damaged links were positioned to generate isolated areas in time distances, rather than taking complete random positioning. For example, horizontally positioned links nos. 105 and 107 were supposed to be damaged and the network was cut off to a large extent in order to generate isolated areas. Also, node no.25 was surrounded by damaged links to generate a local isolated area.

Table 5. Damaged link data

Damaged Link Number	Node-A	Node-B	Amount of damage	Saturation restoration capacity	Minimum number of workers required	Minimum number of construction machines required	Minimum amount of materials required
1	1	2	937	224	82	25	776
7	2	35	1043	100	33	9	285
14	4	6	330	47	16	3	116
19	6	8	923	80	51	15	467
21	8	9	885	160	79	24	744
23	9	51	479	135	96	30	917
38	17	18	682	203	94	29	890
40	18	22	1027	199	68	21	631
44	21	25	887	124	44	13	398
48	23	24	567	160	56	17	512
50	24	36	717	206	57	17	526
51	25	27	448	75	53	16	482
53	26	28	921	22	18	4	130
80	41	46	940	214	104	33	993
90	48	49	647	247	93	29	883
93	49	57	516	178	86	27	819
100	56	61	1183	84	25	6	209
104	58	59	983	40	34	9	296
105	59	68	613	147	87	27	820
107	61	62	933	238	99	31	949
116	65	66	622	114	80	25	751
117	66	73	715	148	46	13	411
118	66	92	481	23	16	5	50
124	72	90	479	182	89	28	848
149	86	87	1118	114	97	30	925
154	91	94	439	46	24	13	90
169	107	108	229	132	39	11	342
170	108	109	3000	56	75	45	433
171	109	110	2560	153	89	41	441

Table 6. Restoration group data

Restoration Group	number of workers	number of construction machines	amount of materials	Initial Located Node
1	210	50	470	1
2	20	10	370	1
3	50	30	570	4
4	110	40	600	10
5	53	20	130	19
6	160	60	650	31
7	50	20	270	49
8	40	20	470	94
9	80	50	570	81
10	160	60	850	81

4.2 Setting Each Parameter of the GA

Parameters of the GA were set at 200 for population size, 100 for the maximum number of generations, 0.6 for the crossover rate, 0.05 for mutation rate and 2.0 for the selection coefficient. The convergence condition was when the number of generations reached the maximum. Regarding mutation, the case of the TPS-type method by blocking (method (2) of Chapter 2 (2)) is described.

4.3 Calculation Result

Figure13 shows the relationship between the cooperative restoration schedule obtained by decoding the best gene string gained by the GA and the recovery process of the OD accessibility index. Figures 14 and 15 show the behavior of each restoration group in the restoration process.

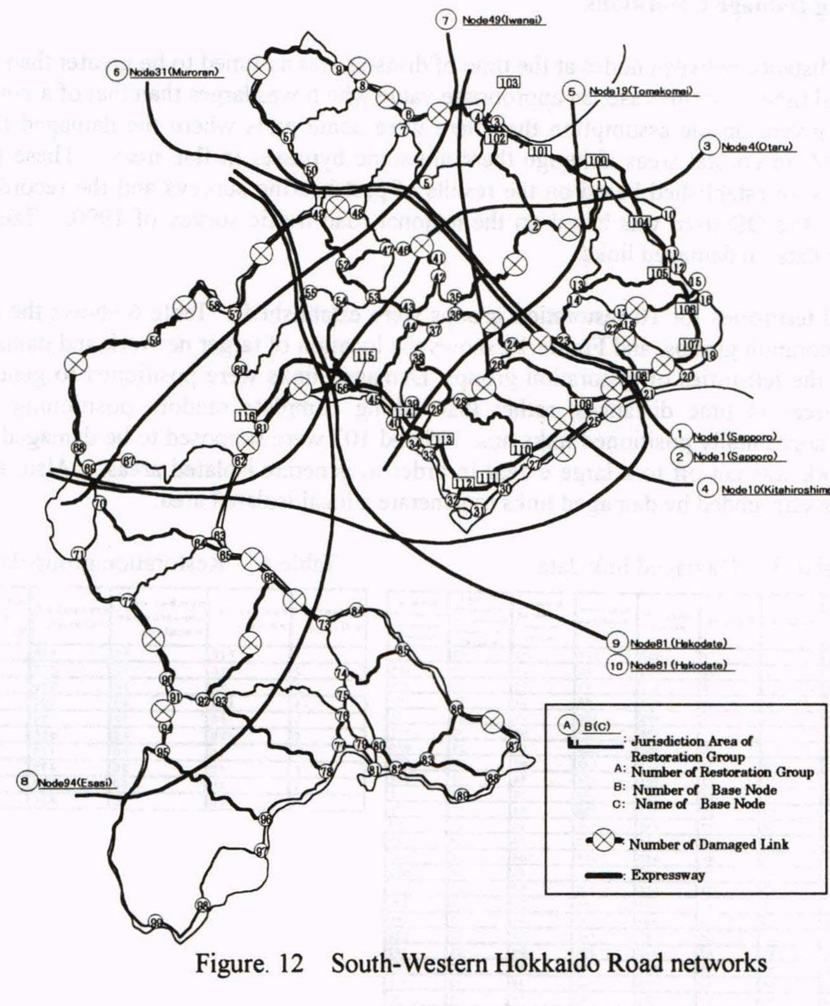

Figure. 12 South-Western Hokkaido Road networks

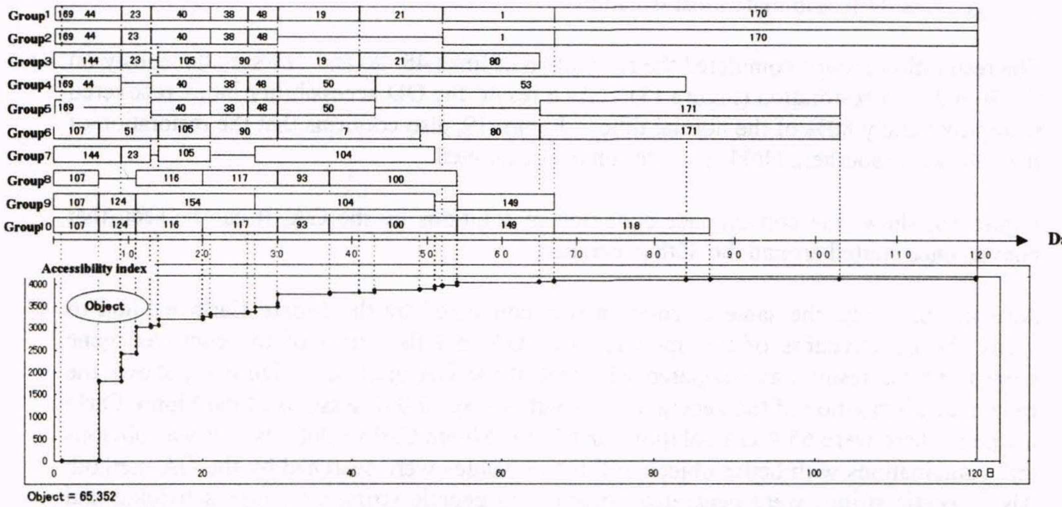

Figure13. Relationship between the cooperation restoration schedule and objective functions obtained by decoding

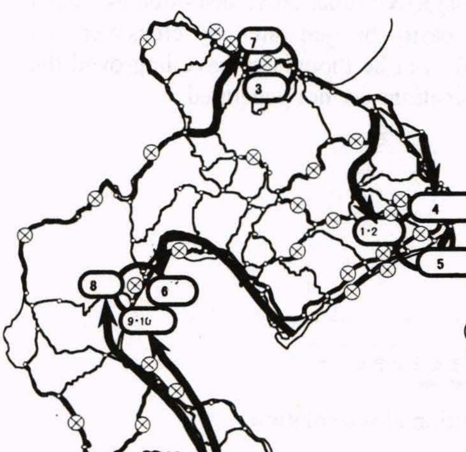

Figure14. Restoration condition immediately after the start of restoration

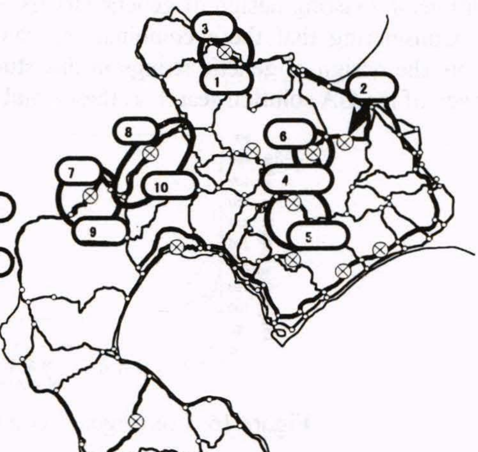

Figure 15. Restoration condition on the 30th day of restoration work

In this study, objective functions are set so that positive values are given if isolation is eliminated at an early stage of restoration. Damaged links are therefore selected to eliminate temporal isolation by relying on cooperation among groups immediately after the start of restoration. For example, groups 9 and 10 restored the damaged link 107 cutting off the network by moving from the assigned node 81 (Hakodate) via detours around damaged links 117 and 116 in cooperation with groups 6 and 8. Groups 1, 2, 4 and 5 restored the damaged link 169 and, from the second day of restoration, restored the damaged link 44 to eliminate local isolation

The restoration groups completed the restoration of links 48, 90 and 117 simultaneously on the 30th day of restoration (Figure.13). As a result, the OD accessibility index recovered to approximately 80% of the normal time. Figure 19, also confirms that the restoration of the network in southern Hokkaido was almost completed.

Figure 16, shows the convergence condition of solutions by the GA. It can be seen that convergence started around the 80th generation.

Also in this study, the same calculation was conducted by the Monte Carlo method to verify the effectiveness of the application of GA and the effect of the contrived gene strings and the result was compared with that of the GA method. Figure 17, shows the frequency distribution of the generation of solutions by 10,000 sessions of the Monte Carlo method. There were 65.4 GA solutions and 173.0 Monte Carlo solutions. It was obvious that combinations with better objective function values were searched by the GA method. Also, genetic strings were generated randomly in genetic string structures satisfying and not satisfying the constrained conditions and compared. As a result, it was confirmed that the searched solution space shifted to the direction with better objective function values by the design of genetic strings in this study. In the frequency distribution of the generation of solutions in existing design of genetic strings, objective function values often exceeded 1,400. Considering that these combinations can easily be generated by crossover and mutation, the design of genetic strings in this study can be thought to have improved the efficiency of the GA solution search as these combinations are not generated.

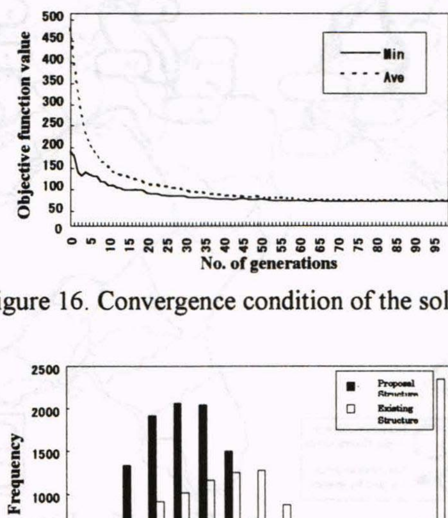

Figure 16. Convergence condition of the solution

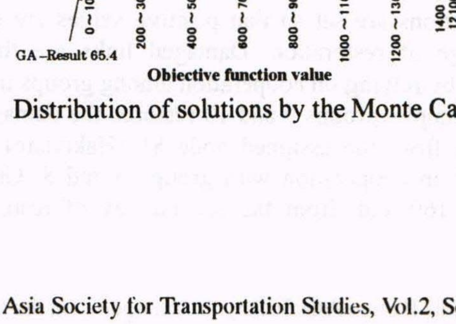

Figure17. Distribution of solutions by the Monte Carlo method

5. CONCLUSION

The purpose of this study was to establish a systematic restoration optimization model by cooperation and to solve a simulated restoration problem. The four main results of this study are as follows:

1) The design method of genetic strings for a scheduling problem was organized and the application of a GA to the optimization problem of the restoration process with the cooperation of multiple restoration groups was presented.
2) As a cooperative restoration problem, contrivances used for coding, crossover and mutation processes were presented so that the genetic strings would always satisfy the combination constraints of restoration groups.
3) As an evaluation model of objective functions in the GA, a model in which "members of restoration groups," "construction machines," "restoration materials," "location assignment of restoration groups," "territories," "damage information of damaged links" and "forms of damaged networks" could be handled freely as variables was established.
4) As a case study, calculation was performed using a national highway-level road network and the improvement of the accuracy of solutions by the ideas of this study was verified.

In this study, recovery of accessibility was set as a single objective function to optimize the solution to a cooperative restoration problem. In reality, however, purposes of restoration may vary greatly, including the connection with the lifeline restoration and securing of routes for emergency vehicles, depending on the scale of the network or the situation of restoration. If it is possible to clarify the relation between the appropriate objective functions and organizations in charge of restoration in each situation and to establish an entire restoration process, a GA can be applied as a multi objectve optimization problem.

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