A Genetic Algorithm Applied to Cutting Stock Problem for Timber Precutting

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Abstract: So far, there are many researches on Bin Packing Problem (BPP). Cutting Stock Problem for timber precutting (CSP) is one of the kinds of BPP. There are some solving methods such as Linear Programming Relaxation method, First Fit method and Minimum Bin Slack method as for this. There are a few papers in which Genetic Algorithm (GA) is applied to BPP. This is because building model is difficult and generating effective individuals of next generation by crossover is also difficult. In this paper, an application of GA to CSP is examined. CSP contains mother materials consisted by several lengths in each grade, shape and species, which is different from general BPP. Therefore we devise double gene structure. Setting control parameter for crossover, an extended elitism method is newly devised. Elitism is extended for the same mother material species and elite group is protected and inherited. Thus, yield rate is improved largely and convergence speed is also improved by this newly proposed method.

Keywords: Genetic Algorithm, Bin Packing Problem, Cutting Stock Problem, Doubled Structure of Gene

1. INTRODUCTION

Cutting Stock Problem for timber precutting (CSP) is one of the kinds of Bin Packing Problem (BPP), which is to combine plural order of timber and cut from the mother materials. CSP contains mother materials consisted by several lengths in each grade, shape and species, which is different from the

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general BPP.

So far, many researches are made on BPP. There are some solving methods such as linear Programming Relaxation method (Ibaragi, 1983), Minimum Bin Slack method (Gupta et al., 1999), First Fit method and Best Fit method as for this. While Genetic Algorithm (GA) is often used to Knapsack Problem and Scheduling Problem which are rather close to BPP. An application of GA to BPP can be seen in the following cases:

• Applying grouping GA which combines local search method and GA (Falkenauer 1994, 1996)

• Special devised crossover method setting combination of bin packing items as gene (Yakawa et al. 2004)

But these cases are rather a few. It may be because of the following reason. Building model is difficult because operation to search bin packing combination patterns is not so easily applied as simple GA is applied to Knapsack Problem.

On the other hand, there are few researches on the concrete theme as CSP. As a matter of fact, precutting factory is managed based on the veteran workers' experience. Generally, the yield rate of materials are said to be under 90%. In this paper, an application of GA to CSP is examined. We devised double gene structure. Setting control parameter for crossover, an extended elitism method is newly devised. Elitism is extended for the same mother material species and elite group is protected and inherited.

The rest of this paper is organized as follows. Definition of CSP is executed in Section 2. GA model is constructed in Section 3. Numeric example is executed in Section 4. Our model is compared with other methods in Section 5. Section 6 is a summary.

2. DEFINITION OF THE PROBLEM

2.1 Cutting Stock Problem for Timber Precutting

Timber precutting for housing is executed based on the mother materials of several lengths (3.5m ~ 6m) in each grade, shape and species. For a general size house, 200 pieces timbers are precut from mother materials in which about 10 pieces are precut from about 20 species.

The object is to maximize the yield rates (Figure 1). Currently, the yield rates of materials are generally said to be 85% to 90% in almost all the precutting factories.
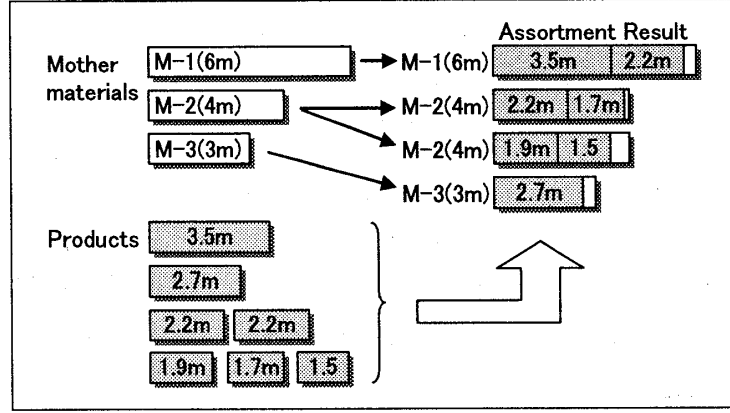
Figure 1. Cutting Stock Problem for Timber Precutting

2.2 Comparison of General BPP and Formulation of CSP

Thus, CSP is one of the BPP. As we have seen CSP before, while BPP handles one kind of bin, CSP handles mother materials of plural lengths and it is said to be a more general problem. We apply GA to mother materials of the same shape, grade and species. First of all, we define 1 dimensional multi BPP which handles plural kinds of bin.

Suppose there are ample bins of m kinds b_t ($t = 1, \cdots, m$). We are to set l_i ($i = 1, \cdots, n$) items in these bins. Then, 1 dimensional multi BPP is stated as follows.

$$\text{Minimize} \quad J = \sum_{t=1}^{m} \sum_{k^{(t)} \in B_t} c_t \tag{1}$$

$$\text{Subject to} \quad \sum_{i \in I_{k^{(t)}}} l_i \le b_t \quad {}^\forall k^{(t)} \in B_t, \ (t = 1, \cdots, m) \tag{2}$$

$$\bigcup_{t=1}^{m} \bigcup_{k^{(t)} \in B_t} I_{k^{(t)}} = I \tag{3}$$

$$I_{k_1} \cap I_{k_2} = \phi \quad {}^\forall k_1, k_2 \in B, k_1 \ne k_2 \tag{4}$$

Where c_t : Cost to use bin species t with capacity b_t

       B_t : Set of used bins of t species.

       $B = \displaystyle\bigcup_{t=1}^{m} B_t$: Set of used bins

$k^{(t)}$ $(=1,2,\cdots)$: Bin in B_t

I_k : Set of items to put in bin k.

I : Set of all items to put in bins.

If the "bin" is replaced by the "timber precutting mother material", "set of bin in each capacity" is replaced by "mother material in each length", "items" are replaced by "products", and "capacity" is replaced by "length", then, above problem becomes CSP. Yield rate is expressed by the following Eq.(5):

$$y = \sum_{i \in I} l_i \left/ \sum_{t=1}^{m} \sum_{k^{(t)} \in B_t} b_t \right. \tag{5}$$

The numerator, which is the total length of products, is given. Therefore, replacing c_t by b_t in Eq.(1), we should pursue Eq.(6) as an objective function.

$$\text{Minimize } J = \sum_{t=1}^{m} \sum_{k^{(t)} \in B_t} b_t \tag{6}$$

A width for sawing waste is required in precutting the materials. Suppose edge trimming is executed before start.

3. MODEL UTILIZING GENETIC ALGRITHM

When applying GA to BPP, following method is used. Listing up bin assignment patterns, and making them as gene, chromosome is set such that it includes all items which should be put in bins. For example, Yakawa et al. (2004) make a gene for the set of items in one bin, and make individual by making array of genes which correspond to each bin. But this method needs to search and evaluate the combination of items which can be set in bin and is not easily applied to the current problem case of plural species of bins.

Using 0, 1 bit array of gene, following method can be considered.

- All products are temporarily assigned to each mother materials using as First Fit method and the sufficient number of mother materials is calculated.
- Then a product is assigned to a certain mother material (Table 1)
- Thus GA model is constructed using 0, 1 bit array.

But even if the number of mother materials could be reduced to the half number of products, chromosome length reaches to $n \times m/2 \times n$ bits in maximum when the number of products is n and the number of mother materials is m. Chromosome of 1,000~3000 bits is required for housing problem stated above. It may be hard to apply. Therefore, the following new model is examined which is stated precisely in the next section.

Table 1. Expression Using 0,1 Bit Array

Mother Material (MM)		Product 1 4,300	Product 2 3,800	Product 3 3,200	Product 4 2,700	Product 5 1,000
length	No. of MM					
6,000	M6000-1	0	0	1	0	1
	M6000-2	1	0	0	0	0
	M6000-3	0	0	0	0	0
4,000	M4000-1	−	0	0	0	0
	M4000-2	−	0	0	0	0
	M4000-3	−	1	0	0	0
3,000	M3000-1	−	−	−	1	0
	M3000-2	−	−	−	0	0

3.1 Structure of the Gene

Yamachi et al. (2006) proposed the following method. When applying GA to the fault tolerant system of software system, assigning the order of task combination is proposed using gene expressed by random numbers. This is the method to assign locus task by order. Locus is sorted in order by the key of gene.

In this paper, model is built such that chromosome is expressed by the order of products (Order based representation), and double gene structure is devised. Double gene structure is as follows.

  • Gene-B : Gene which assign mother material species.
  • Gene-P : Gene which assign order in mother materials of the same species
      (Table. 2).

Set variables and sets as follows:

$I = \{i \mid i = 1,2,\cdots,n\}$: Set of products.

l_i : Length of product i.

t_i : Mother material species to which product i is assigned.

B_t : Set of mother material species t ($t = 1,2,\cdots,m$).

$k^{(t)}$ ($= 1,2,\cdots$) : Mother material in B_t.

b_t : Length of mother material $k^{(t)}$.

Then, gene of product i is defined as follows.

GeneB : t_i ($1 \leq t_i \leq m$) \hfill (7)

where $b_{t_i} \geq l_i$, ($i = 1,2,\cdots,n$) \hfill (8)

GeneP : s_i ($0 \leq s_i \leq 1$) $\cdots$ sorting key by assortment order \hfill (9)

Table 2. A Gene Structure

Product = Locus	1	2	$\cdots$	n	Contents of Control
GeneB	t_1	t_2	$\cdots$	t_n	Assign mother material species.
GeneP	s_1	s_2	$\cdots$	s_n	Sorting key by assortment order

As assortment calculation is executed by the following method, which is newly devised (Figure 2).

3.2 Extended Elitism Method

By the method stated above, slight changes of Gene-P cause the changes of assignment order of product and the assignment to mother material changes by this. To avoid this condition, following control is considered, which makes the control to keep the condition that mother material and product groups of high yield rate are inherited preferentially in order to develop stable optimal solution.

Control 1: Products of high yield rate group in combination with mother materials must be assigned prior to other products in order to keep high yield rate.

Control 2: Products gene of high yield rate group in combination with

Step 1: Set GeneB as the first key and GeneP as the second key. Sort the products by these keys.

     Set product order as $i = 1, 2, \cdots, n$ after sorting.

Step 2: Set t_1 of the first product ($i = 1$) as t_c.

     Set mother material $k^{(t_c)} = 1$ in the mother material species t_c.

Step 3: For product i,

     ① If GeneB $t_i \neq t_c$, assign the product to a new mother material $k^{(t_i)} = 1$ in the mother material species t_i

     and set $t_c \leftarrow t_i$.

     ② If GeneB $t_i = t_c$ and $\displaystyle\sum_{j \in I_{k^{(t_c)}}} l_j + l_i \leq b_{t_c}$, assign the product to the same mother material $k^{(t_c)}$.

     ③ If GeneB $t_i = t_c$ and $\displaystyle\sum_{j \in I_{k^{(t_c)}}} l_j + l_i > b_{t_c}$, assign the product to a new mother material $k^{(t_c)} + 1$ in the

     same mother material species t_c and set $k^{(t_c)} \leftarrow k^{(t_c)} + 1$.

     where $I_{k^{(t)}}$ is a set of products assigned to mother material $k^{(t)}$.

Step 4: Set $i \leftarrow i + 1$, and go to Step 3

Figure 2. The Newly Devised Algorithm

mother materials must be inherited to the next generation even if crossover is executed.

Generally, elitist selection is executed to the each individual, but in this case, we extend elitism to the each gene of the individual in order to select the best possible gene group. Therefore, we name this as "Extended Elitism Method".

Snipping rate $r_{k^{(t)}}$ ($0 \leq r_{k^{(t)}} \leq 1$) of mother material $k^{(t)}$ is expressed as follows:

$$r_{k^{(t)}} = (b_t - \sum_{j \in I_{k^{(t)}}} l_j) \Big/ b_t = 1 - \sum_{j \in I_{k^{(t)}}} l_j \Big/ b_t \tag{10}$$

Where the last term of Eq. (10) is the yield rate of mother material $k^{(t)}$.

In order to establish Control 1 stated above, define GeneP as follows:

$$\text{GeneP:} \quad s_i = r_{k^{(t_i)}} \quad 0 \leq s_i \leq 1, \quad i = 1, 2, \cdots, n \tag{11}$$

GeneP is the snipping rate of the product group in combination with mother material which is calculated by Eq. (10) when each assortment is executed. It has a small value when yield rate is high.

Furthermore, in order to establish Control 2, we introduce Crossover Control Parameter (CCP) p_i and set it as the crossover probability.

$$\text{CCP:} \quad p_i = F_p\,(r_{k^{(a_i)}}) \quad 0 \leq p_i \leq 1, \quad i = 1,2,\cdots,n \tag{12}$$

F_p which is a CCP Function, is an increasing function to snipping rate. In detail, it is discussed in the next section.

3.3 Flow of Newly Devised Algorithm

Flow of newly devised algorithm is exhibited in Figure. 3.

A. Initial Population

Random number $1 \leq t_i \leq m$ is set to GeneB t_i for each individual. Random number $0 < s_i < 1$ is set to GeneP s_i for each individual. GeneB must satisfy Eq.(8). By this method, generate initial population to the prefixed number.

B. Calculation of Assortment and Fitness Ratio

Assignment is executed by the rule stated in the previous section and then following B-1 and B-2 operation is executed.

B-1. Calculation of Fitness Ratio

Fitness ratio a is obtained by Eq.(13) in which it is scaled by Fitness Function F_a.

$$\text{Fitness ratio:} \quad a = F_a(y), \text{ where } y \text{ is a yield rate.} \tag{13}$$

Yield rates are nearly 70% and minimum values are 50%~60% by the trial experiment when random assortment is executed. We want to have an objective yield rate to be more than 90%. Based on these, new function $F_a(y)$ should be set such that: a is nearly 0 when $y < 0.5$ and a changes greatly between $0.6 < y < 1.0$.

B-2. Calculation of Snipping Ratio and Revision of GeneP

A snipping rate is calculated by Eq.(10) from the assortment results. Then GeneP is revised by Eq.(11).
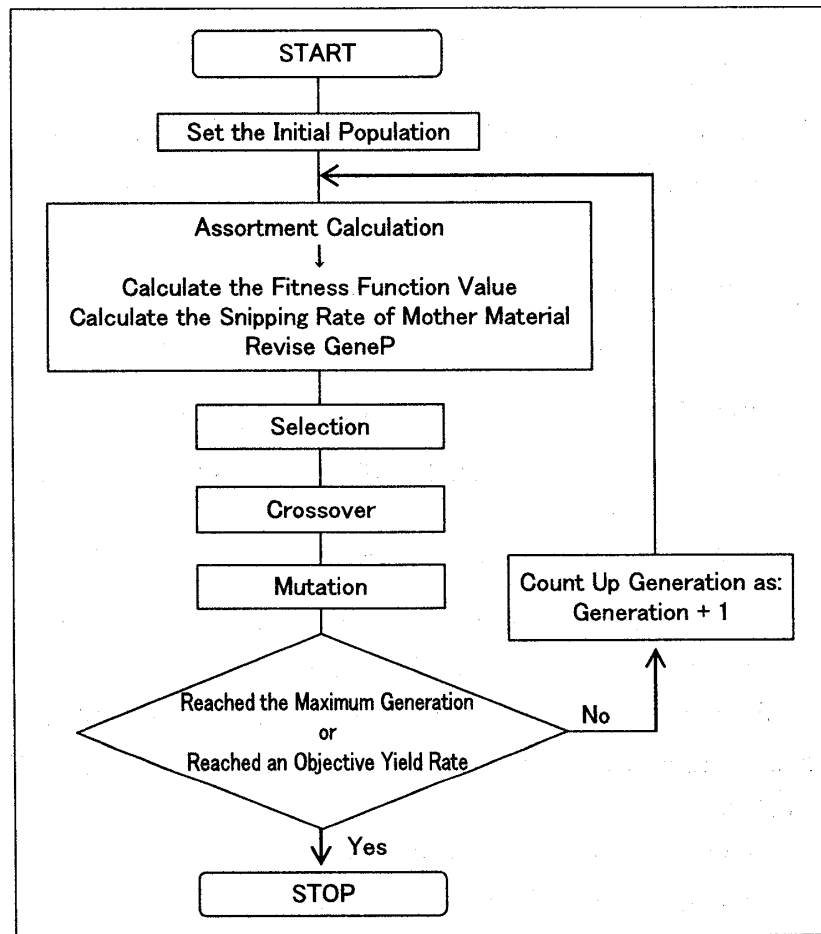
Figure 3. The Flow of the Newly Devised Algorithm

C. Selection

Selection is executed by the combination of the general elitist selection and the roulette wheel selection. Elitism is executed until the number of new elites reaches the predetermined number. After that, roulette wheel selection is executed and selected.

D. Crossover

The number of decreased individuals by selection is increased to the number of initial population by adding crossover result. Therefore, the number of individuals does not change by generation.

Generally, crossover is executed from 2 parents to 2 children using one-point crossover or multi-point crossover or uniform crossover. In this paper,

we take extended elitism method. That is, 2 children are generated by exchanging genes of 2 parents following CCP.

Set i-th locus GeneB of individual X as $t_i(X)$, and also set those of GeneP as $s_i(X)$, CCP as $p_i(X)$ in the same way. Then, generate next generation by the following rules:

Child 1 : If p_i(Parent 1)$>Rnd$, then　t_i(Child 1)$=t_i$(Parent 2), s_i(Child 1)$=s_i$(Parent 2)

$$\qquad\qquad\qquad \text{else}\quad t_i\text{(Child 1)}=t_i\text{(Parent 1)}, \ s_i(\text{ Child 1})=s_i\text{(Parent 1)} \tag{14}$$

Child 2 : If p_i(Parent 2)$>Rnd$, then　t_i(Child 2)$=t_i$(Parent 1), s_i(Child 2)$=s_i$(Parent 1)

$$\qquad\qquad\qquad \text{else}\quad t_i\text{(Child 2)}=t_i\text{(Parent 2)}, \ s_i(\text{ Child 2})=s_i\text{(Parent 2)} \tag{15}$$

Where, *Rnd* is a (0, 1) random number.

p_i is set by Eq.(12). Trial experiment shows that many individuals which performed the yield rate more than 90% have snipping rate less than 0.1%. If we set an objective yield rate to be more than 90%, snipping rate should be aimed to be under 0.05%. Therefore, the following setting method of F_p would be effective:

1) $F_p(r)$ is nearly 0 when r is around 0.
2) $F_p(r)$ changes rapidly when r is near 0.05.
3) $F_p(r)$ is set such that gene exchange is executed to a certain degree when $r>0.1$.

E. Mutation

As we handle the two kind of gene, we set mutation probability for each gene and make mutation operation by selecting individuals based on the probability set. When GeneB has mutation, GeneP is also set to have mutation, applying the condition of Eq.(8). When mutation occurs in GeneP, GeneB is not changed.

F. Termination

When an object yield rate is achieved or the operation reached maximum generation, the procedure is terminated.

4. APPLYING TO HOUSING TIMBER PRECUTTING PROBLEM

A typical order of a house is exhibited in Table 3. The total number of materials is 199. These are divided into 18 groups considering the characteristics of each material. Parameters are set as follows based on the trial experiment.

$$
\left.\begin{array}{l}
\text{Selection probability} = 50\% \quad \text{General elitism selection is not adopted.}\\[4pt]
\text{GeneB : Mutation probability} = 10\%\\[4pt]
\qquad \text{Mutation locus number} = 10\% \text{ of product number (round up)}\\[4pt]
\text{GeneP : Mutation probability} = 10\%\\[4pt]
\qquad \text{Mutation locus number} = 10\% \text{ of product number (round up)}\\[4pt]
\text{A width for sawing waste} = 5\text{mm} \quad \text{Trimming loss} = 0
\end{array}\right\} \quad (16)
$$

F_a is set to be a 1st order linear function. F_p is set to be a function close to sigmoid function (Figure 4).

$$
a = F_a(y) = \begin{cases} (10/55)y & y < 0.55 \\ 2y - 1 & \text{else} \end{cases} \tag{17}
$$

$$
p_i = F_p(r_{k(t_i)}) = \begin{cases} 2400\, r_{k(t_i)}^{3} & r_{k(t_i)} < 0.05 \\ \min\{\, 0.8(r_{k(t_i)} - 0.05)^{1/4} + 0.3,\, 1\} & \text{else} \end{cases} \tag{18}
$$
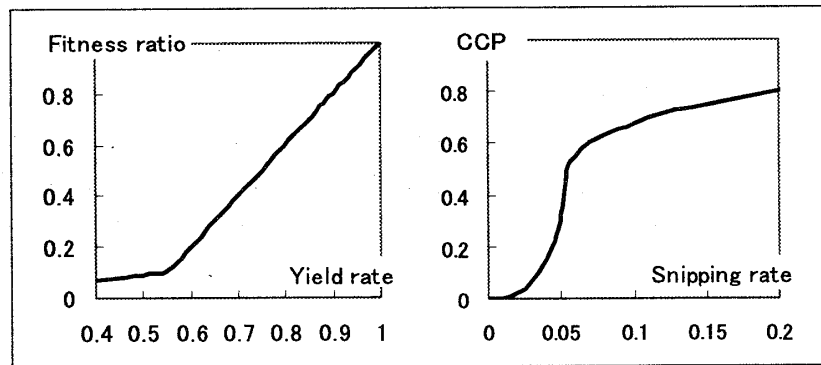
Figure 4. F_a (Left) and F_p (Right)

Table 3. Housing precutting materials

Lot No.	Shape (mm)	Species	Grade	Mother Material species	Products	
					Number	Volume(m^3)
1	105×105	323	292	3	38	0.8881
2	105×105	801	292	3	13	0.2910
3	240×105	328	294	6	14	1.0869
4	210×105	328	293	5	5	0.3275
5	180×105	328	293	5	22	0.9224
6	150×105	328	293	5	2	0.0710
7	120×105	328	293	5	23	0.4600
8	105×105	328	292	3	1	0.0083
9	270×105	328	294	5	1	0.1064
10	240×105	328	294	6	4	0.3786
11	210×105	328	293	5	4	0.2975
12	180×105	328	293	5	3	0.1437
13	150×105	328	293	5	8	0.3297
14	120×105	328	293	5	11	0.2552
15	105×105	328	292	3	15	0.3267
16	210×105	328	293	5	3	0.2601
17	105×105	49	7	2	4	0.1107
18	90×90	49	7	2	28	0.4959
Total					199	6.7596

4.1 Experimental Result

Programming surrounding is exhibited in Table 4. Experimental result is exhibited in Table 5. The data in Table 4 are an average, maximum, minimum for 50 times iteration and their sample data are exhibited in Appendix A-1 and A-2.

As for the lots, of which products number is less than 5, have the same value for 50 times iteration and they are assumed to be an optimal solution. The variance of almost all rots lie within 0.5%. Exceptional cases are lot No.12 and lot No.14. As for the case of lot No.12, yield rate of 80% to 90% occurred twice and the yield rate of the rest of the case was 96.22% in maximum.

Adopting the cases which take the maximum yield rate, timber precutting can be executed in 95.21% yield rate for one house which requires 199 products.

Table 4. Environment of programming

Hardware	Type of Machine	IBM Think Pad G41
	CPU	Intel Pentium 3GHz
	Memory	512 MByte
Software	OS	Windows XP
	Programming Language	MS Excel VBA, MS Excel 2002

Table 5. Experimental result (50 times iteration)

Lot No.	Mother Material species	Products		Number of Individuals	Number of Generation	Yield rate				Average processing time (sec)
		Number	Volume (m³)			Maximum	Average	Minimum	S.D.	
1	3	38	0.8881	500	200	96.91%	96.67%	95.76%	0.30%	18
2	3	13	0.2910	300	100	96.34%	96.34%	96.34%	0.00%	2
3	6	14	1.0869	300	100	97.58%	97.46%	96.71%	0.28%	2
4	5	5	0.3275	100	100	92.82%	92.82%	92.82%	0.00%	0
5	5	22	0.9224	400	200	94.40%	94.27%	94.03%	0.09%	8
6	5	2	0.0710	100	50	92.02%	92.02%	92.02%	0.00%	0
7	5	23	0.4600	400	200	98.67%	97.67%	96.33%	0.41%	8
8	3	1	0.0083	10	10	25.00%	25.00%	25.00%	0.00%	0
9	5	1	0.1064	10	10	93.85%	93.85%	93.85%	0.00%	0
10	6	4	0.3786	100	100	95.69%	95.69%	95.69%	0.00%	0
11	5	4	0.2975	100	100	89.93%	89.93%	89.93%	0.00%	0
12	5	3	0.1437	100	50	96.22%	95.76%	84.46%	2.21%	0
13	5	8	0.3297	300	100	96.01%	96.00%	95.58%	0.09%	2
14	5	11	0.2552	300	100	98.81%	96.66%	94.21%	0.83%	2
15	3	15	0.3267	300	100	96.46%	96.21%	95.34%	0.46%	2
16	5	3	0.2601	100	50	98.31%	98.31%	98.31%	0.00%	0
17	2	4	0.1107	100	50	83.64%	83.64%	83.64%	0.00%	0
18	2	28	0.4959	400	200	92.76%	92.76%	92.76%	0.00%	10
Total		199	6.7596			95.21%				

4.2 Evaluation of Extended Elitism Method

Hereafter, we examine the lot No. 1 in detail because it has relatively a large value of standard deviation and the number of products is also large. Fitness Function F_a and CCP Function F_p are evaluated. Table 6 shows the comparative combination of those. Parameters are same except for the Case 7. Figure 5 shows the behavior of each function.

Table 7 shows the experimental result after 50 times iteration. Comparing Case 1 to Case 5, we can confirm that Fitness Function does not have much influence on convergence. On the other hand, CCP Function has an influence on convergence. If we set appropriate shape of the function, we can get good convergence. That is, the gene crossover control by CCP plays an important role for convergence and extended elitism seems to make much more

influence on selection than other methods.

To confirm this, we compared this with the case where CCP is not reflected to crossover. Case 6 is the result that crossover is executed by a uniform crossover. Case 7 is the result that 5% selection by elitism (25 individuals) is executed prior to the roulette wheel selection using fitness ratio. Figure 6 shows the transition of yield rate (maximum, average, minimum) by generation for the two cases of Original Model and Case 6. We can find that the convergence is unstable when CCP is not reflected to crossover. Namely, it is confirmed that "Concept of schema can not be built and evolution to a stable optimal solution can not be expected". In this case, yield rate improves slightly by adding the general elitist selection (Table 7 - Case 7). But convergence process is very slow compared with the Original Model. Thus, the effectiveness of gene exchange control by crossover using CCP is clarified.

Table 6. Comparative Combination of Fitness Function and CCP Function

	Fitness Function		CCP Function	
Case 1	$a = y$	(19)	Eq.(18): Original	
Case 2	$1/(1 + \exp(-16(y - 0.75)))$	(20)	Eq.(18): Original	
Case 3	Eq.(17): Original		$p_i = r_{k(i)}$	(21)
Case 4	Eq.(17): Original		$p_i = \log(r_{k(i)} + 0.01)/4.7 + 0.98$	(22)
Case 5	Eq.(17): Original		$p_i = 0.8/(1 + \exp(-100(r_{k(i)} - 0.05)))$	(23)
Case 6	Eq.(17): Original		Do not use CCP → Uniform crossover	
Case 7	Same combination as Case6 and 5% of individuals are selected by the general elitist selection rule			
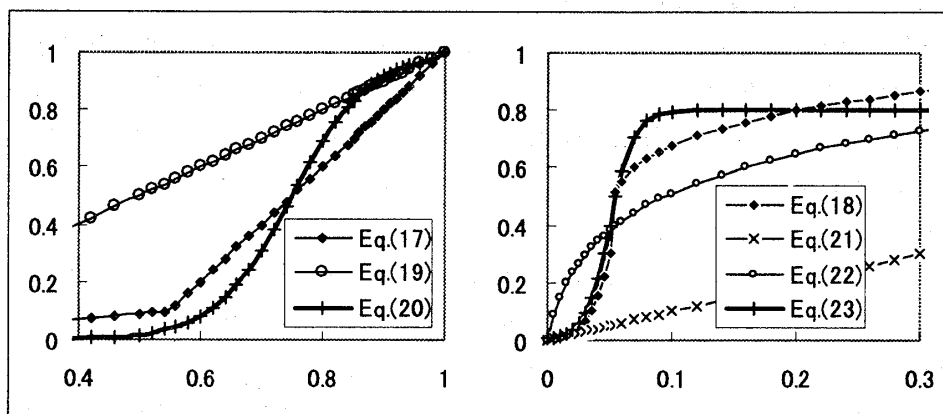
Figure 5. Fitness Function (Left) and CCP Function (Right)

Table 7. Experimental result for 50 times iteration by the cases
(Lot No.1)

Cases	Maximum	Average	Minimum	S.D.
Original	96.91%	96.67%	95.76%	0.30%
Case 1	96.91%	96.50%	95.76%	0.37%
Case 2	96.91%	96.56%	95.76%	0.36%
Case 3	96.17%	95.49%	94.68%	0.36%
Case 4	96.17%	95.85%	94.99%	0.28%
Case 5	96.91%	96.63%	95.76%	0.28%
Case 6	93.54%	91.29%	89.74%	0.84%
Case 7	94.99%	93.01%	90.39%	0.83%
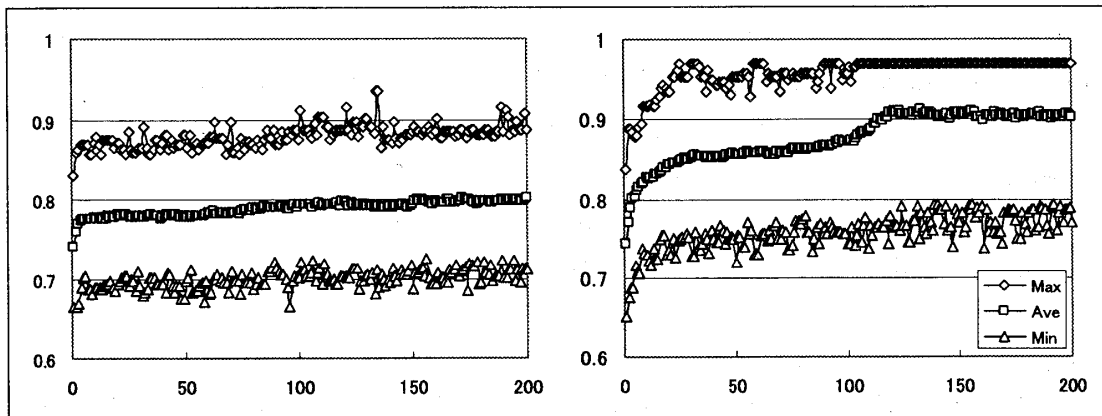
Figure 6. Transition Yield Rate by Generation
(Left: Case6, Right: Original Model)

5. COMPARISON WITH OTHER ALGORITHMS

In comparing the newly proposed method with other algorithms, an application example of GA to timber precutting problem can not be found except for the patent (Murata, 2001). Therefore, we compare the newly proposed method with the patent. We also made comparison with First Fit Descending (FFD) Method which are revised to this problem.

5.1 An Algorithm of the Patent

An Algorithm of the Patent (Japan Patent No. 3565262) is as follows.

　　1) Calculate the sum of length of all products
　　2) List up the combination of mother materials of which total length surpass above length calculated.
　　3) Judge whether all products can be assigned to mother materials or not
　　4) Search the minimum length combination of mother materials in which all products can be assigned.
　　5) Investigate the combination of mother materials which minimize mother materials' length.

5.2 Revised First Fit Descending Algorithm

FFD Algorithm is a general solving method in BPP. In this timber precutting problem, it can not be applied because there are plural species of mother materials. Toyoda et al. (2007) proposed a revised FFD (RFFD) algorithm for the BPP model which includes plural species of mother materials. This method is to repeat the process of assigning products to each mother material of these species and adopting the assignment result with maximum yield rate until all products are assigned.

5.3 Comparison of results

In Table 8, the newly proposed method, the patent method and RFFD method are compared (In detail, see Appendix A-2). As a result, the newly proposed method is superior to the patent method for 0.6% in the yield rate and superior to RFFD method for 0.8%. Especially, it is good for the Lot No. 1 and the Lot No. 7 which have many combination patterns.

Considering that yield rates are under 90% in the general timber precutting factory, the newly proposed method shows extremely effective result. This is derived by the fact that Extended Elitism Method using crossover control by CCP promoted the evolution to an optimal solution effectively and stably.

6. CONCLUSION

So far, many researches were made on Bin Packing Problem (BPP). Cutting Stock Problem for timber precutting (CSP) was one of the kind of BPP. There were some solving methods such as Linear Programming Relaxation method, First Fit method and Minimum Bin Slack method as for this. There

Table 8. Result of Yield Rate

Lot No.	Proposed Method	Patent Algorithm	RFFD Algorithm
1	96.91%	95.67%	95.76%
2	96.34%	96.34%	96.34%
3	97.58%	96.27%	97.36%
4	92.82%	92.82%	92.82%
5	94.40%	94.03%	94.22%
6	92.02%	92.02%	92.02%
7	98.67%	97.36%	95.57%
8	25.00%	25.00%	25.00%
9	93.85%	93.85%	93.85%
10	95.69%	95.69%	95.69%
11	89.93%	89.93%	89.93%
12	96.22%	96.22%	96.22%
13	96.01%	96.01%	96.01%
14	98.81%	96.92%	94.65%
15	96.46%	95.34%	92.37%
16	98.31%	98.31%	98.31%
17	83.64%	83.64%	83.64%
18	92.76%	92.76%	92.76%
Total	95.21%	94.60%	94.45%

were a few papers in which Genetic Algorithm (GA) was applied to BPP. This was because building model was difficult and generating effective individuals of next generation by crossover was also difficult.

In this paper, an application of GA to CSP was examined. CSP contained mother materials consisted by several lengths in each grade, shape and species, which was different from general BPP. Therefore we devised double gene structure. Setting control parameter for crossover, an extended elitism method was newly devised. Elitism was extended for the same mother material species and then elite group was protected and inherited. Thus, yield rate was improved largely and convergence speed was also improved by this newly proposed method. Various solving method should be examined hereafter.

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Appendix Table A-1. Sample of Calculation

Iteration	Lot No.												
	1	2	3	4	5	6	7	···	14	15	16	17	18
1	96.54%	96.34%	96.71%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
2	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.46%	95.34%	98.31%	83.64%	92.76%
3	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
4	96.91%	96.34%	97.36%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
5	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
6	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	96.33%	···	94.65%	95.34%	98.31%	83.64%	92.76%
7	96.13%	96.34%	97.36%	92.82%	94.40%	92.02%	98.14%	···	96.46%	96.46%	98.31%	83.64%	92.76%
8	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	94.65%	96.46%	98.31%	83.64%	92.76%
9	96.91%	96.34%	96.71%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
10	96.87%	96.34%	96.71%	92.82%	94.40%	92.02%	97.62%	···	96.46%	96.46%	98.31%	83.64%	92.76%
11	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.36%	···	96.92%	96.46%	98.31%	83.64%	92.76%
12	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
13	96.13%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
14	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.46%	96.46%	98.31%	83.64%	92.76%
15	96.87%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
16	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	95.10%	96.46%	98.31%	83.64%	92.76%
17	96.87%	96.34%	96.71%	92.82%	94.22%	92.02%	96.58%	···	94.21%	96.46%	98.31%	83.64%	92.76%
18	96.54%	96.34%	96.71%	92.82%	94.22%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
19	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
20	96.91%	96.34%	97.36%	92.82%	94.22%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
21	96.50%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
22	96.13%	96.34%	97.58%	92.82%	94.40%	92.02%	98.14%	···	96.46%	96.46%	98.31%	83.64%	92.76%
23	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	98.14%	···	96.92%	96.46%	98.31%	83.64%	92.76%
24	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.46%	95.34%	98.31%	83.64%	92.76%
25	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	98.67%	···	96.92%	96.46%	98.31%	83.64%	92.76%
26	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
27	96.50%	96.34%	97.58%	92.82%	94.22%	92.02%	98.67%	···	96.46%	96.46%	98.31%	83.64%	92.76%
28	95.76%	96.34%	97.58%	92.82%	94.22%	92.02%	97.36%	···	96.46%	96.46%	98.31%	83.64%	92.76%
29	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
30	96.91%	96.34%	97.36%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
31	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	95.46%	98.31%	83.64%	92.76%
32	96.54%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
33	96.50%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
34	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	98.67%	···	98.81%	95.34%	98.31%	83.64%	92.76%
35	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
36	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
37	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.36%	···	98.81%	96.46%	98.31%	83.64%	92.76%
38	96.87%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
39	96.54%	96.34%	97.58%	92.82%	94.22%	92.02%	97.36%	···	94.65%	96.46%	98.31%	83.64%	92.76%
40	96.50%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
41	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.88%	···	96.92%	96.46%	98.31%	83.64%	92.76%
42	96.13%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	95.34%	98.31%	83.64%	92.76%
43	96.13%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
44	96.50%	96.34%	96.71%	92.82%	94.22%	92.02%	97.62%	···	95.10%	96.46%	98.31%	83.64%	92.76%
45	96.17%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
46	96.50%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
47	96.50%	96.34%	97.58%	92.82%	94.03%	92.02%	97.36%	···	96.92%	96.46%	98.31%	83.64%	92.76%
48	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
49	96.91%	96.34%	97.58%	92.82%	94.22%	92.02%	98.67%	···	96.92%	96.46%	98.31%	83.64%	92.76%
50	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	97.62%	···	96.92%	96.46%	98.31%	83.64%	92.76%
MAX	96.91%	96.34%	97.58%	92.82%	94.40%	92.02%	98.67%	···	98.81%	96.46%	98.31%	83.64%	92.76%
AVE	96.67%	96.34%	97.46%	92.82%	94.27%	92.02%	97.67%	···	96.66%	96.21%	98.31%	83.64%	92.76%
MIN	95.76%	96.34%	96.71%	92.82%	94.03%	92.02%	96.33%	···	94.21%	95.34%	98.31%	83.64%	92.76%
S.D	0.30%	0.00%	0.28%	0.00%	0.09%	0.00%	0.41%	···	0.83%	0.46%	0.00%	0.00%	0.00%

Appendix Table A-2. Sample of GA and RFFD's Calculation Results
(mm)

Lot	Genetic Algorithm Materials	Products				Yield Rate	RFFD Materials	Products					Yield Rate
1	4000	3236.0	750.0			99.65%	4000	3846.0					96.15%
	4000	2144.0	1784.0			98.20%	4000	3846.0					96.15%
	4000	2694.0	1219.6			97.84%	3680	3604.0					97.93%
	4000	2844.0	1050.0			97.35%	3680	3555.0					96.60%
	4000	2009.0	992.0	874.0		96.88%	3680	3490.0					94.84%
	4000	3846.0				96.15%	3680	3437.0					93.40%
	4000	3846.0				96.15%	4000	3236.0	750.0				99.65%
	4000	2294.0	1634.0			98.20%	3680	3137.0					85.24%
	3680	1859.0	1784.0			98.99%	3000	2992.5					99.75%
	3680	2645.0	992.0			98.83%	4000	2844.0	1050.0				97.35%
	3680	3604.0				97.93%	4000	2844.0	1050.0				97.35%
	3680	874.0	2694.0			96.96%	4000	2694.0	1219.6				97.84%
	3680	874.0	2694.0			96.96%	3680	2694.0	874.0				96.96%
	3680	3555.0				96.60%	3680	2694.0	874.0				96.96%
	3680	3490.0				94.84%	3680	2645.0	992.0				98.83%
	3680	3437.0				93.40%	4000	2294.0	1634.0				98.20%
	3680	3137.0				85.24%	4000	2144.0	1784.0				98.20%
	3000	2992.5				99.75%	3000	2096.5	874.0				99.02%
	3000	1050.0	1934.0			99.47%	4000	2009.0	1934.0				98.58%
	3000	1934.0	1039.7			99.12%	3000	1934.0	1039.7				99.12%
	3000	874.0	2096.5			99.02%	3680	1859.0	1784.0				98.99%
	3000	1392.0	1542.0			97.80%	3000	1542.0	1392.0				97.80%
	3000	2844.0				94.80%	3000	992.0	874.0				62.20%
	83120	**80554.3**				**96.91%**	**84120**	**80554.3**					**95.76%**
7	6000	2607.0	1634.0	874.0	869.0	99.73%	4500	2715.0	1634.0				96.64%
	6000	1934.0	1934.0	1934.0		96.70%	4900	2694.0	2192.0				99.71%
	4500	1784.0	2694.0			99.51%	4500	2694.0	1784.0				99.51%
	4500	2715.0	874.0	874.0		99.18%	4900	2694.0	1934.0				94.45%
	4500	874.0	874.0	2694.0		98.71%	6000	2607.0	1934.0	1024.0			92.75%
	4500	874.0	2694.0	874.0		98.71%	4900	1934.0	1934.0	874.0			96.78%
	4000	874.0	2192.0	874.0		98.50%	4500	874.0	874.0	874.0	874.0	874.0	97.11%
	3000	1934.0	1024.0			98.60%	4000	874.0	874.0	874.0	869.0		87.28%
	37000	**36509.0**				**98.67%**	**38200**	**36509.0**					**95.57%**
15	4000	874.0	874.0	2239.0		99.68%	3680	3517.0	0.0				95.57%
	3680	2607.0	1024.0			98.67%	4000	2952.0	1024.0				99.40%
	3680	1784.0	1784.0			96.96%	3680	2725.0	874.0				97.80%
	3680	1784.0	1784.0			96.96%	3680	2694.0	874.0				96.96%
	3680	3517.0				95.57%	3680	2607.0	750.0				91.22%
	3000	2239.0	750.0			99.63%	3000	2239.0	0.0				74.63%
	3000	2952.0				98.40%	3000	2239.0	0.0				74.63%
	3000	2725.0				90.83%	3680	1784.0	1784.0				96.96%
	3000	2694.0				89.80%	3680	1784.0	1784.0				96.96%
	30720	**29631.0**				**96.46%**	**32080**	**29631.0**					**92.37%**
18	4000	2112.5	1841.5			98.85%	4000	3775.0					94.38%
	4000	2759.0	1157.5			97.91%	4000	3607.0					90.18%
	4000	2759.0	1157.5			97.91%	4000	3587.5					89.69%
	4000	1007.5	1500.0	1352.5		96.50%	4000	3320.0					83.00%
	4000	1944.5	1917.5			96.55%	4000	3042.0					76.05%
	4000	1849.0	1955.0			95.10%	4000	2975.0	1007.5				99.56%
	4000	3775.0				94.38%	4000	2975.0	1007.5				99.56%
	4000	3607.0				90.18%	4000	2759.0	1157.5				97.91%
	4000	3587.5				89.69%	4000	2759.0	1157.5				97.91%
	4000	1500.0	2372.5			96.81%	3000	2717.5					90.58%
	4000	3320.0				83.00%	4000	2372.5	1500.0				96.81%
	4000	3042.0				76.05%	4000	2262.5	1500.0				94.06%
	3000	2975.0				99.17%	4000	2112.5	1849.0				99.04%
	3000	2975.0				99.17%	4000	1955.0	1944.5				97.49%
	3000	1917.5	1007.5			97.50%	4000	1917.5	1917.5				95.88%
	3000	1352.5	1500.0			95.08%	4000	1841.5	1500.0				83.54%
	3000	2717.5				90.58%	3000	1352.5	1352.5				90.17%
	3000	2262.5				75.42%							
	66000	**61224.5**				**92.76%**	**66000**	**61224.5**					**92.76%**
				Total Yield Rate=		95.21%				Total Yield Rate=			94.45%