Optimization in Allocating Goods to Shop Shelves Utilizing Genetic Algorithm under the Introduction of Sales Probabilities

Asami Shitara¹, Yuki Higuchi², Daisuke Takeyasu³ and Kazuhiro Takeyasu⁴

1. Tax Corporation Arknet, Shizuoka City, Japan

2. Faculty of Business Administration, Setsunan University, 17-8 Ikeda-nakamachi, Neyagawa, Osaka, 572-8508, Japan

3. Graduate School of Culture and Science, The Open University of Japan, 2-11 Wakaba, Mihama-District, Chiba City 261-8586, Japan

4. College of Business Administration, Tokoha University 325 Oobuchi, Fuji City, Shizuoka 417-0801, Japan

Abstract: How to allocate goods in shop shelves makes great influence to sales amount. Searching best fit allocation of goods to shelves is a kind of combinatorial problem. This becomes a problem of integer programming and utilizing genetic algorithm may be an effective method. Reviewing past researches, there are few researches made on this. Formerly, we have presented a paper concerning optimization in allocating goods to shop shelves utilizing genetic algorithm. In those papers, the problem that goods were not allowed to allocate in multiple shelves and the problem that goods were allowed to allocate in multiple shelves were pursued. In this paper, we examine the problem that allows goods to be allocated in multiple shelves and introduce the concept of sales profits and sales probabilities. Optimization in allocating goods to shop shelves is investigated. Expansion of shelf is executed. Utilizing genetic algorithm, optimum solution is pursued and verified by a numerical example. Various patterns of problems must be examined hereafter.

Key words: Display, genetic algorithm, optimization, shelf.

1. Introduction

Displaying method in the shop makes influence to sales amount, therefore various ideas are devised. What kind of items should be placed where in the shop, how to guide customers to what aisle in the shop are the big issues to be discussed. Searching best fit allocation of goods to shelves is also an important issue to be solved. In this paper, we seek how to optimize in allocating goods to shop shelves.

As for allocating good to shop shelves, following items are well known [1-3].

Shelf height is classified as follows.

Shelf of 135 cm height: Customers can see the

whole space of the shop. Specialty stores often use this type.

Shelf of 150 cm height: Female customers may feel pressure to the shelf height. This height may be the upper limit to look over the shop.

Shelf of 180 cm height: It becomes hard to look over the shop. Therefore it should not be used for island display (display at the center or inside the shop).

Next, we show the following three functions of shelf for display:

- (1) Exhibition of goods function
- (2) Stock function
- (3) Display function

Effective range for exhibition is generally said to be 45 cm-150 cm. The range of 75 cm-135 cm is called golden zone especially. For the lower part under 45

Corresponding author: Kazuhiro Takeyasu, Ph.D., professor, research fields: marketing and optimization. E-mail: takeyasu@fj.tokoha-u.ac.jp.

cm, goods are stocked as well as displaying.

2. Literature Review

Reviewing past papers, there are many papers concerning lay out problem. As for the problem of the distribution of equipment, we can see Refs. [4-6] for the general research book. There are many researches made on this. Wu and Yamada et al. [7-9] handle this problem considering aisle structure. Ito and Irohara [10] considers multi-floor facility problem.

Although there are many researches on corresponding theme as stated above, we can hardly find researches on the problem of optimization in allocating goods to shop shelves.

Formerly, we have presented a paper concerning optimization in allocating goods to shop shelves utilizing genetic algorithm [11]. In those papers, the problem that goods were not allowed to allocate in multiple shelves and the problem that goods were allowed to allocate in multiple shelves were pursued. In this paper, we examine the problem that allows goods to be allocated in multiple shelves and introduce the concept of sales profits and sales probabilities. Expansion of shelf is executed. Optimization in allocating goods to shop shelves is investigated. Utilizing genetic algorithm, optimum solution is pursued and verified by a numerical example.

The rest of the paper is organized as follows: Problem description is stated in Section 3; Genetic Algorithm is developed in Section 4; Numerical example is exhibited in Section 5 which is followed by the remarks of section 6; Section 7 is a summary.

3. Problem Description

Shelf model is constructed as Fig. 1. There are five shelf positions. Shelf position 1 is mainly to put big and heavy goods including stock function. Shelf position 3, 4 at the height of the range 75 cm to 135 cm are the space of golden zone. Thus, we can use shelves properly by assuming these shelves. In

numerical example, we examine using these five shelves. First of all, we make problem description in the case there is only one shelf (case 1). Then we expand to the case there are multiple shelves (case 2).

(1) Case 1: The case that there is only one shelf

Although there are few cases that there is only one shelf, it makes the foundation for multiple shelves case. Therefore we pick it up as a fundamental one. Suppose shelf position k is from 1 to L (Fig. 2).

Suppose there are N amount of goods ($i = 1, \dots, N$). Set sales profit of goods i as H^i .

Table 1 shows the sales probabilities when each goods is placed at each shelf position. The values in this table are written for example.

Suppose goods are sold in the period from t_1 to t_n . In addition, a new goods i is replenished when goods i is sold out.

Set the accumulated sales probability of goods i in time zone t , shelf j , and shelf position k in the table as $HK_{t,j,k}^i$.

Then, the sales probability $K_{t_1/t_n}^{i,j,k}$ of goods i in the period will be described as follows.

Fig. 1 Shelf model.

k	L
k	3
k	2
k	1

Fig. 2 Shelf position.

Table 1 Sales probability for each goods.

Day of the Week	Time Zone (t)	Shelf $j=1$		Shelf $j=2$		...		Shelf $j=m$	
		Shelf position		Shelf position		...		Shelf position	
		$k=1$	... $k=L_1$	$k=1$	... $k=L_2$	...	$k=1$	... $k=L_m$	
(Mon.)	0-1 ($t=1$)	0.01	...						
	1-2 ($t=2$)	0.02							
	...								
(Tue.)	23-24 ($t=24$)	0.03							
	0-1 ($t=25$)	0.02							
	1-2 ($t=26$)	0.02							
...	...								
	23-24 ($t=48$)	0.03							
	...								
(Sun.)	0-1 ($t=145$)	0.02							
	1-2 ($t=146$)	0.03							
	...								
	23-24 ($t=168$)	0.04							

$k = L_1$	$k = L_2$	...	$k = L_m$
$\vdots$	$\vdots$		$\vdots$
$k = 3$	$k = 3$		$k = 3$
$k = 2$	$k = 2$		$k = 2$
$k = 1$	$k = 1$		$k = 1$
$j = 1$	$j = 2$		$j = m$

Fig. 3 Shelf position under multiple shelves.

$$K_{t_1/t_n}^{i,j,k} = \sum_{t=1}^n HK_{t,j,k}^i$$

This can take the value more than 1. For example, the value 2 means that 2 amount of goods were sold during the period.

Set Benefit in the sales period from t_1 to t_n as $P_{t_1/t_n}^{i,j,k}$ ($i=1, \dots, N$) ($j=1, \dots, m$) ($k=1, \dots, L$) where goods i is placed at shelf j and shelf position k .

Where, benefit means:

$$\text{Benefit} = \text{SalesProbability} \times \text{SalesProfit}$$

Therefore, this equation is represented as follows:

$$P_{t_1/t_n}^{i,j,k} = K_{t_1/t_n}^{i,j,k} \cdot H^i \quad (1)$$

where, $j=1$ because one shelf case is considered here.

Set $x_{i,k}$ as:

$x_{i,k} = 1$: Goods i is placed at shelf position k .

$x_{i,k} = 0$: Else

Suppose only one goods can be placed at one shelf position and also suppose that goods is allowed to allocate in multiple shelf positions. Then constraints are described as follows:

$$x_{i,k} = 1, 0 \quad (i=1, \dots, N) \quad (k=1, \dots, L) \quad (2)$$

$$\sum_{i=1}^N x_{i,k} = 1 \quad (k=1, \dots, L) \quad (3)$$

Under these constraints,

$$\text{Maximize } J = \sum_{k=1}^L \sum_{i=1}^N P_{t_1/t_n}^{i,j,k} x_{i,k} \quad (4)$$

(2) Case 2: The case that there are m shelves

Suppose there are m shelves (Fig. 3). Set Benefit as:

$$P_{t_1/t_n}^{i,j,k} \quad (i = 1, \dots, N), \quad (j = 1, \dots, m), \quad (k = 1, \dots, L_j)$$

where goods i is placed at shelf position k of shelf j . The sales period is the same with above stated (1).

Set $x_{i,j,k}$ as:

$x_{i,j,k} = 1$: Goods is placed at shelf position k of shelf j

$x_{i,j,k} = 0$: Else

Suppose only one goods can be placed at one shelf position and also suppose that goods is allowed to allocate in multiple shelf positions. Then constraints are described as follows. The sales period is the same with before.

$$x_{i,j,k} = 1, 0 \quad (i = 1, \dots, N) \quad (j = 1, \dots, m) \quad (k = 1, \dots, L_j) \quad (5)$$

$$\sum_{i=1}^N x_{i,j,k} = 1 \quad (j = 1, \dots, m) \quad (k = 1, \dots, L_j) \quad (6)$$

Under these constraints,

$$\text{Maximize } J = \sum_{i=1}^N \sum_{j=1}^m \sum_{k=1}^{L_j} P_{t_1/t_n}^{i,j,k} x_{i,j,k} \quad (7)$$

4. Algorithm

We can make problem description as stated above, although these are somewhat under restricted cases. As far as only these are considered as they are, there is little difference between these and the conventional optimization problems. However, as soon as the number of involved shelves becomes larger, the number of variables dramatically grows greater, to which the application of Genetic Algorithm solution and Neural Network solutions may be appropriate. There are various means to solve this problem. When that variable takes the value of 0 or 1, the application of genetic algorithm would be a good method. As is well known, the calculation volume reaches numerous or even infinite amounts in these problems when the number of variables increases. It is reported that GA is effective for these problems [12-14].

A. The Variables

Suppose the number of goods, shelf position, and shelf are 20, 5, 3 respectively. In this paper, shelf

position is expanded from 2 to 3. Then the number of variables becomes three hundred.

$$x_{i,j,k} = 1, 0 \quad (i = 1, \dots, 20) \quad (j = 1, 2, 3) \quad (k = 1, \dots, 5)$$

Therefore, set chromosome as follows.

$$\begin{aligned} X = & (x_{1,1,1}, x_{2,1,1}, x_{3,1,1}, \dots, x_{20,1,1}, \\ & x_{1,1,2}, x_{2,1,2}, x_{3,1,2}, \dots, x_{20,1,2}, \\ & \vdots \\ & x_{1,1,5}, x_{2,1,5}, x_{3,1,5}, \dots, x_{20,1,5}, \\ & x_{1,2,1}, x_{2,2,1}, x_{3,2,1}, \dots, x_{20,2,1}, \\ & x_{1,2,2}, x_{2,2,2}, x_{3,2,2}, \dots, x_{20,2,2}, \\ & \vdots \\ & x_{1,2,5}, x_{2,2,5}, x_{3,2,5}, \dots, x_{20,2,5}, \\ & x_{1,3,1}, x_{2,3,1}, x_{3,3,1}, \dots, x_{20,3,1}, \\ & x_{1,3,2}, x_{2,3,2}, x_{3,3,2}, \dots, x_{20,3,2}, \\ & \vdots \\ & x_{1,3,5}, x_{2,3,5}, x_{3,3,5}, \dots, x_{20,3,5}) \end{aligned} \quad (8)$$

B. Initialize population

Initialization of population is executed. The number of initial population is M . Here set $M = 100$. Set gene at random and choose individual which satisfies constraints.

C. Selection

In this paper, we take elitism while selecting. Choose P individuals in the order which take maximum score of objective function.

Here, set $P = 20$

D. Crossover

Here, we take uniform crossover.

Set crossover rate as:

$$P_c = 0.7 \quad (9)$$

E. Mutation

Set mutation rate as:

$$P_m = 0.01 \quad (10)$$

Algorithm of GA is exhibited at Table 2.

Introducing the variable y_s such that:

$$y_s = i \quad (11)$$

Table 2 Algorithm of multi-step tournament selection method.

Step 1	Set maximum No. as $g_{\max}$, population size as P , crossover rate as p_c , mutation rate as p_m .
Step 2	Set $t = 1$ for generation No. and generate initial solution matrix $x_p(t) = (x_{i,j,k}^p) \ (p = 1, \dots, M)$.
Step 3	Calculate Objective function $J(x_p(t))$ for all solution matrix $x_p(t) \ (p = 1, \dots, P)$ in generation t .
Step 4	Set $t = t + 1$ until $t > g_{\max}$.
Step 5	Crossover Generate new individual by crossover utilizing the method of above stated D .
Step 6	Mutation Reproduce by mutation utilizing the method of above stated E .
Step 7	Calculate objective function for reproduction of generation t .
Step 8	Selection Next generation is selected by elitism. Go to Step 4.

where,

$$s = k + (j - 1) \cdot 5 \quad (12)$$

when

$$x_{i,j,k} = 1$$

then Eq. (8) is expressed as:

$$Y = (y_1, y_2, \dots, y_{15}) \quad (13)$$

5. Numerical Example

Now, we execute numerical example using POS sales data. Numerical example is executed in “Case 2” of 3 (2). Suppose the sales period is 5 days for Monday through Friday. Table 3 shows the unit sales profit H^i of each goods.

Supposing a general daytime retail store, we set opening time to be 9 through 18 o'clock. Table 4 shows the sales probabilities of lot i as an example.

Table 5 shows the sales probability by shelf for each shelf position. Table 6 shows the value in which Table 4 and Table 5 are multiplied. Table 7 shows the benefit Table in which accumulated probability of Table 6 and Sales Profit of Table 3 are multiplied.

In Table 5, shelf $j=2$ is located near the entrance therefore the table value reflects this condition.

Table 7 shows the benefit when each goods is placed at each shelf position of each shelf.

Experimental results are as follows. The expression Eq. (8) is complicated. Therefore we use expression by Eq. (13). A sample set of initial population is

exhibited in Table 6.

Convergence process is exhibited in Fig. 4.

The problem is simple, so combination of genotype for crossover saturates in the 170th generation. Genotype in which objective function becomes maximum is as follows:

$$Y = (20, 20, 10, 17, 17, 18, 18, 1, 11, 11, 20, 20, 11, 17, 17)$$

Table 3 Unit sales price and sales profit of each goods.

Lot i	Sales price	H^i	
1		6,000	
2		5,500	
3		5,500	
4		5,000	
5		4,500	For Women
6		4,500	
7		4,000	
8		3,500	
9		3,000	
10		3,000	
11		6,000	
12		5,500	
13		5,000	For Men
14		4,500	
15		4,000	
16		3,500	
17		3,000	
18		4,000	
19		3,000	For Kids
20		2,000	

Table 4 Sales probability of Lot i (Time Zone).

Day of the week	Time Zone(t)	Sales probability	Day of the week	Time Zone(t)	Sales probability
(Mon.)	9-10		(Thu.)	9-10	
	10-11			10-11	
	11-12			11-12	
	12-13			12-13	
	13-14			13-14	
	14-15			14-15	
	15-16			15-16	
	16-17			16-17	
	17-18			17-18	
(Tue.)	9-10		(Fri.)	9-10	
	10-11			10-11	
	11-12			11-12	
	12-13			12-13	
	13-14			13-14	
	14-15			14-15	
	15-16			15-16	
	16-17			16-17	
	17-18			17-18	
(Wed.)	9-10		(Sat.)	9-10	
	10-11			10-11	
	11-12			11-12	
	12-13			12-13	
	13-14			13-14	
	14-15			14-15	
	15-16			15-16	
	16-17			16-17	
	17-18			17-18	

Table 5 Sales probability of Lot i (Shelf Position).

Shelf $j=1$					Shelf $j=2$					Shelf $j=3$				
Shelf position					Shelf position					Shelf position				
$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$
0.7	0.9	1.2	1.2	0.9	0.8	1.0	1.3	1.3	1.0	0.8	0.9	1.2	1.3	1.1

This coincides with the result of optimal solution by the calculation of all considerable cases, therefore it coincides with a theoretical optimal solution. We take up simple problem and we can confirm the effectiveness of GA approach. Further study for complex problems should be examined hereafter.

6. Remarks

As there are few papers made on this theme, we constructed prototype version before [11]. In this paper, we examined the problem that allowed goods to

be allocated in multiple shelves and introduced the concept of sales profits and sales probabilities. An application to the shop with POS sales data was executed. We can see that genetic algorithm is effective for this problem.

In practice, following themes occur.

Sales probabilities should be arranged correctly.

There are various types of shelves corresponding to goods characteristics (For example, cold storage goods).

Furthermore, genotype must be devised in construction when there are huge number of goods and shelves.

Table 6 Sales probability of Lot i .

Day of the week	Time Zone(t)	Shelf j=1					Shelf j=2					Shelf j=3				
		Shelf position					Shelf position					Shelf position				
		$k=1$	$k=2$	$k=3$	$k=4$	$k=5$	$k=4$	$k=5$	$k=3$	$k=4$	$k=5$	$k=1$	$k=2$	$k=3$	$k=4$	$k=5$
(Mon.)	9-10															
	10-11															
	11-12															
	12-13															
	13-14															
	14-15															
	15-16															
	16-17															
	17-18															
(Tue.)	9-10															
	10-11															
	11-12															
	12-13															
	13-14															
	14-15															
	15-16															
	16-17															
	17-18															
(Sat.)	9-10															
	10-11															
	11-12															
	12-13															
	13-14															
	14-15															
	15-16															
	16-17															
	17-18															

Table 7 Benefit table.

Lot i	Shelf 1					Shelf 2					Shelf 3				
	Shelf position					Shelf position					Shelf position				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	2,580	4,380	5,400	5,220	4,380	5,220	7,020	7,980	7,800	7,020	2,780	4,880	5,650	5,800	5,180
2	2,750	4,620	5,610	5,390	4,620	5,005	6,820	7,810	7,590	6,820	2,950	5,120	5,860	6,000	5,420
3	3,025	4,840	5,830	5,610	4,840	4,840	6,600	7,590	7,425	6,600	3,225	5,340	6,100	6,200	5,640
4	3,200	5,000	6,000	5,800	5,000	4,600	6,400	7,400	7,200	6,400	3,400	5,500	6,250	6,400	5,800
5	3,420	5,130	6,750	6,345	5,130	4,230	6,750	7,830	7,560	6,660	3,45	5,670	7,110	6,975	5,985
6	3,600	5,400	6,390	6,210	5,400	4,185	5,985	7,020	6,795	5,985	3,800	5,900	7,150	6,800	6,200
7	3,800	5,600	6,600	6,400	5,600	4,000	5,800	6,800	6,600	5,800	4,000	6,100	6,650	7,000	6,400
8	3,990	5,810	6,790	6,615	5,810	3,815	5,600	6,615	6,405	5,600	4,200	6,310	6,850	7,200	6,600
9	4,200	6,000	6,900	6,810	6,000	3,600	5,400	6,300	6,210	5,400	4,400	6,500	7,050	7,400	6,800
10	4,410	6,210	7,200	6,990	6,210	3,390	5,190	6,210	6,000	5,190	4,610	6,710	7,150	7,600	7,000
11	2,220	4,980	5,820	6,000	5,580	4,200	7,020	7,800	7,980	7,620	2,420	5,500	7,450	6,600	6,400
12	2,420	5,225	5,995	6,215	5,830	4,015	6,820	7,590	7,810	7,425	2,620	5,720	6,070	6,820	6,600

(table 7 continued)

Lot i	Shelf 1					Shelf 2					Shelf 3				
	Shelf position					Shelf position					Shelf position				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
13	2,600	5,400	6,200	6,400	6,000	3,800	6,600	7,400	7,600	7,200	2,800	5,900	6,250	7,000	6,800
14	2,790	5,580	6,390	6,615	6,210	3,600	6,390	7,200	7,380	7,020	3,000	6,100	6,450	7,210	7,000
15	3,000	5,800	6,600	6,800	6,400	3,400	6,200	7,000	7,200	6,800	3,200	6,300	6,650	7,400	7,200
16	3,185	5,985	6,790	7,000	6,615	3,185	5,985	6,790	7,000	6,615	3,400	6,500	6,850	7,600	7,400
17	3,390	6,240	6,990	7,200	6,810	3,000	5,790	6,600	6,810	6,390	3,600	6,700	7,050	7,800	7,600
18	6,800	6,800	3,200	2,400	200	8,000	8,000	4,400	3,400	1,400	7,000	7,300	6,450	3,000	1,000
19	6,990	6,990	3,390	2,610	390	7,800	7,800	4,200	3,210	1,200	7,200	7,500	6,650	3,200	1,200
20	7,200	7,200	3,600	2,800	600	7,600	7,600	4,000	3,000	1,000	7,400	7,700	6,850	3,400	1,400

Table 6 A sample set of initial population.

$Y_1 =$	(	7	20	2	9	9	5	19	5	17	14	19	4	9	12	20	)
$Y_2 =$	(	11	14	4	13	11	16	11	3	5	18	10	8	5	9	12	)
$Y_3 =$	(	12	18	10	15	2	20	4	12	19	15	3	7	1	18	13	)
						$\vdots$											
$Y_{98} =$	(	11	2	6	12	20	12	18	16	9	9	9	15	20	14	5	)
$Y_{99} =$	(	9	16	6	11	3	18	6	3	10	6	12	9	3	3	16	)
$Y_{100} =$	(	8	12	4	17	15	12	13	7	14	2	11	8	6	12	5	)

Fig. 4 Convergence process of case 2.

For these issues, expanded version of the paper will be built hereafter consecutively. As for 1, constraints are relaxed than those of this paper. As for 2,

expansion is easy to make. As for 3, constructing genotype from the shelf side would bear much more simple expression.

7. Conclusion

How to allocate goods in shop shelves makes great influence to sales amount. Searching best fit allocation of goods to shelves is a kind of combinatorial problem. This becomes a problem of integer programming and utilizing genetic algorithm may be an effective method. Reviewing past researches, there were few researches made on this. Formerly, we had presented papers concerning optimization in allocating goods to shop shelves utilizing genetic algorithm. In those papers, the problem that goods were not allowed to allocate in multiple shelves and the problem that goods were allowed to allocate in multiple shelves were pursued. In this paper, we examined the problem that allowed goods to be allocated in multiple shelves and introduced the concept of sales profits and sales probabilities. Expansion of shelf was executed. Optimization in allocating goods to shop shelves was investigated. Utilizing genetic algorithm, optimum solution was pursued and verified by a numerical example. Various patterns of problems should be examined hereafter.

References

- [1] Nagashima, Y. 2005. *Shop Arrangement and Displaying (in Japanese)*. Nihon Jitsugyo Press.
- [2] Atsumi, S. 2008. *Shop Lay Out (in Japanese)*. Jitsumu Kyoiku Press.
- [3] Kohno, H. 2006. *Making Charming Shop (in Japanese)*. Paru Press.
- [4] Korte, B., and Vygeu, J. 2005. *Combinatorial Optimization*. Springer.
- [5] Gen, M., and Cheng, R. 1997. *Genetic Algorithms & Engineering Design*. JOHN WILEY & SONS, INC.
- [6] Michalewicz, Z. 1999. *Genetic Algorithms + Data Structures = Evolution Programs*. Springer.
- [7] Wu, Y., and Appleton, E. 2002. "The Optimization of Block Layout and Aisle Structure by a Genetic Algorithm." *Computers & Industrial Engineering* 41: 371-82.
- [8] Yamada, T., Irohara, T., and Fujikawa, H. 2004. "Design Methodology for the Facility Layout Problem to Consider the Aisle Structure and Intra-Department Material Flow." *JIMA* 55: 111-20.
- [9] Yamada, T., and Irohara, T. 2006. "Detailed Layout Design Methodology Using Mixed Integer Programming and Simulated Annealing." *JIMA* 57: 39-50.
- [10] Ito, T., and Irohara, T. 2006. "Multi-floor Facility Layout Technique Including Determination of Detailed I/O Location." *JIMA* 57: 395-403.
- [11] Takeyasu, K., and Higuchi, Y. 2008. "Optimization in Allocating Goods to Shop Shelves." *The Journal of Economic Studies* 54: 55-64.
- [12] Arial, M., and Masui, Y. 2006. "Optimization of Maritime Container-Transportation Network through the Use of Genetic Algorithm." *Japan Ship-Marine Engineering Society* 4: 55-61.
- [13] Gen, M., Ida, K., and Li, Y. 1995. "Solving Multi Objective Solid Transportation Problem by Genetic Algorithm." *JIMA* 46: 445-54.
- [14] Toyama, H., Ida, K., and Teramatsu, C. 2006. "A Proposal of a Genetic Algorithm for Fixed-Charge Transportation Problem and Related Numerical Experiments." *JIMA* 57: 227-30.