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A Method for Standardizing Parts with Integer Programming

Liu DONG*, Yasuhiro KAJIHARA*, Hirokazu OSAKI* and Yoshiomi MUNESAWA*
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A method for standardizing parts is proposed. This method aims to reduce the sort of parts for cutting the manufacturing cost and for improving specifications of parts. Two linear mathematical programming models are proposed for standardizing the parts. One model aims at cutting cost half without causing any degradation of mechanical specifications of parts. The other model aims at doubling mechanical specifications of parts below the acceptable manufacturing cost. These models are formulated in 0−1 integer programming forms. The integer programming model shows which part is common to other parts. An example is shown to demonstrate the use of the developed method.

1. INTRODUCTION

The variety of parts has increased to satisfy varied consumer preference and demand. It has direct influence on the manufacturing cost because it brings the hike of the inventory cost of materials, and forces the kind of assembly JIGs and fixtures to increase. Therefore, the standardization of the parts has become indispensable to reduce the manufacturing cost. So far group technology (GT) [1] and variety reduction (VR) [2] have been used to achieve the above purpose. GT aims at decreasing the kind of parts whose dimension is different. VR aims at decreasing the kind of parts whose specification is different. However, the manufacturing cost has not been considered in these methods. If we can reduce the manufacturing cost of parts more than fifty percent without any degradation of specifications, then the reduction improves our competitive power. If we improve the mechanical specification of parts more than fifty percent under the acceptable manufacturing cost, then the improvement also makes our competitive power stronger. In this paper, we assume that the manufacturing cost is made up of the material cost, processing cost and assembly cost and propose two models of standardizing parts for reducing the manufacturing cost and for improving the mechanical specifications drastically. 0−1 Integer programming models are developed to solve the standardization models.

2. PROPOSED METHOD

In this study, the standardization means to reduce the sort of parts based on the common points of parts. Two methods are proposed. (1) Standardization that aims at reducing the cost and minimizing degradation of mechanical specification. (2) Standardization that aims at manufacturing parts with the maximum specification below the acceptable raised manufacturing cost. The process of the standardization of parts is as follows. First, manufacturing cost and mechanical specifications of all parts are clarified. Next, parts are standardized based on the specifications of each part and the manufacturing cost (material cost, processing cost and assembly cost).

2.1 Symbols and assumptions

The following symbols will be used in this method.

G_i : i−th product (i=, ⋯ ,N)

P_{ij} : j−th part of product G_i (j=1, ⋯ ,NR)

* Department of Mechanical Engineering

The following specifications of the parts are considered.

(1) Dimensional specifications: length of sides (k=1), the number of hole (k=2), longitudinal and width ratio (k=3), volume (k=4), progression (k=5)

(2) The specifications in use: temperature(k=6), speed(k=7), revolutions per minute(k=8), generating power(k=9)

The specifications of each part are measured. K−th specification of the part P_{ij} is shown by a symbol (FX_{ijk}). If a part Pij has nothing to do with the k−th specification, we set the FXijk=0.

2.2 Relative specification and manufacturing cost of parts

The dimension and scale of specifications are different. So, we transform each specification into non−dimensional one. The non−dimensional specification is given by the equation (1), and called the relative specification (f_{ijk}) . The relative specification (f_{ijk}) achieved from the equation (1) is ($0 \leq f_{ijk} \leq 1$).

$$f_{ijk}=\frac{FX_{ijk}-\min_{1\leq i\leq N}\{FX_{ijk}\}}{\max_{1\leq i\leq N}\{FX_{ijk}\}-\min_{1\leq i\leq N}\{FX_{ijk}\}} \quad \begin{matrix}(j=1,\cdots,NR)\\(k=1,\cdots,NKj)\end{matrix} \qquad (1)$$

The manufacturing cost is made up of material cost, processing cost and assembly cost. In this method, we suppose that following costs are given. material cost (CSij), processing cost (CMij), assembly cost (CAij).

The manufacturing cost of the part C_{ij} is given in the equation (2) based on the above costs.

$$C_{ij}=CCS_{ij}+CCM_{ij}+CCA_{ij} \qquad (2)$$

Two models are proposed for standardizing the selected parts to reduce the cost. One method aims at cost reduction without causing any degradation of relative specifications. The other method aims at satisfying the upper limit of cost and maximizing the relative specifications.

2.3 Cost reduction amount achieved by the standardization of parts

From above assumption, we evaluate the cost reduction amount that is achieved by the standardization. The reduced amount differs depending on the combination of the parts that are standardized. We use Diqj to show the reduced amount achieved by changing the part Pij to the part Pqj. The reduced amount is given by the equation (3).

$$D_{iqj} = C_{ij} - C_{qj} \qquad (3)$$

When the amount Diqj is positive, the manufacturing cost will be cut by the standardization. Each reduced amount of all the combination is shown in Table 1.

Table 1 Cost reduction amount by the standardization

(from) \ (to)	P1j	P2j	…	PNj
P1j	\	D12j	…	D1Nj
P2j		\		D2Nj
⋮			\	
PNj				\

2.4 Change of part specification by the standardization

We show all the specifications of all parts in Table 2. The k−th relative specification of part (P_{ij}) is shown by f_{ijk} . When a part P_{ij} is changed to a part P_{iq}, change of the relative specification DF_{ijq} is given by the equation (4).

$$DF_{ijq}=\sum_{K=1}^{NK}(f_{ijk}-f_{iqk}) \qquad (4)$$

Change of the relative specification is evaluated by the equation (4) for all the combinations of all parts and shown in

Table 2 The relative specifications

	fij1	fij2	…	fijNK
Pi1	fi11	fi12	…	fi1NK
Pi2	fi21	fi22	…	fi2NK
⋮	⋮	⋮	…	⋮
PiNR	fiNR1	…	…	fiNRNK

Table 3. From the equation (4), when DF_{ijq} is positive, the specification of the part P_{ij} is degraded. Conversely, specification is improved when DF_{ijq} is negative.

Table 3 The change of the relative specification by the standardization

	P_{1j}	P_{2j}	…	P_{Nj}
P_{1j}		DF_{12j}	…	DF_{1Nj}
P_{2j}	DF_{21j}		…	DF_{2Nj}
⋮	⋮	⋮		⋮
P_{Nj}	DF_{N1j}	…	…	

2.5 Variables for the standardization

The standardization is carried out in consideration of cost and specifications. We use a variable X_{iqj} for representing whether a part is changed to other one. The variable is defined as follows:

$$X_{ijq}=\begin{cases}1 : \text{(Part } P_{ij} \text{ is changed to the part } P_{qj}\text{)}\\ 0 : \text{(Part } P_{ij} \text{ is not changed to the part } P_{qj}\text{)}\end{cases}$$

Variable X_{ijq} is set in all the combinations of all the parts as shown in Table 4.

Table 4 The variables in standardization models

	P_{i1}	P_{i2}	…	P_{is_i}
P_{i1}		X_{i12}	…	X_{i1s_i}
P_{i2}				⋮
⋮				⋮
P_{is_i}			…	

2.6 Model 1 (The standardization minimizing degradation of specifications)

The aim of the first standardization model is to reduce cost with minimum degradation of relative specifications.

(1)Objective function (minimizing degradation of specifications)

The integer programming model presented below shows which part is common to other parts. The aim of this objective function is to minimize total degradation of specification. The total degradation of specification (Z) is determined by summing up the degradation of specification of all the combinations as shown in Table 3. The minimum value of Z is given in the equation (5).

$$\min Z=\sum_{i=1}^{N}\sum_{j=1}^{S_i}(DF_{ij}X_{ij2}+DF_{ij2}X_{ij2}+\cdots+DF_{ijs_i}X_{ijs_i}) \qquad (5)$$

Constraints for determining the new specifications of all the parts are given by the equation (6) −(8) below.

(2) Constraint 1 (achievement of cost reduction)

The total amount of cost reduction of all the parts should exceed the amount set in the plan model as shown in the equation (6).

$$\sum_{i=1}^{N}\sum_{j=1}^{S_i}(D_{ij}X_{ij1}+\cdots+D_{ijs_i}X_{ijs_i}) > T \qquad (6)$$

Here the symbol T represents the target figure of the cost reduction.

(3) Constraint 2

The part (P_{ij}) is not able to be made common to more than two kinds of parts. This condition is shown in the equation (7).

$$1-(X_{ij1}+X_{ij2}+\cdots+X_{ijs_i})\geq 0 \qquad (i=1,\cdots,r)\ ,\ \ (j=1,\cdots,S_i) \qquad (7)$$

(4) Constraint 3

After a standardization, difference (Z) of a relative specification of part P_{ij} is given by the next equation.

$$DZ_{ij}=DF_{ij1}X_{ij1}+DF_{ij2}X_{ij2}+\cdots+DF_{ijs_i}X_{ijs_i}$$

As the minimum value LM_{ij} which degrades relative specifications of the P_{ij} is given, a restricted condition is given in the equation (8).

$$DZ_{ij}>LM_{ij} \qquad (i=1,\cdots,r)\ ,\ \ (j=1,\cdots,S_i) \qquad (8)$$

In summary, the entire model minimizing degradation of the specification is presented in a 0−1 integer programming form with all constraints as shown below.

objective function:

$$\max Z=\sum_{i=1}^{N}\sum_{j=1}^{Si}(DF_{ij1}X_{ij2}+DF_{ij2}X_{ij2}+\cdots+DF_{ijsi}X_{ijsi})$$

constraints: equations (6)−(8)

$X_{ijk}=0$ or $X_{ijk}=1$, $\forall_{i,j,k}$

2.7 Model 2 (The standardization maximizing the functional improvement)

For the second model, we set the upper limit of the manufacturing cost and maximize the relative specification of parts without exceeding that limit.

(1) Objective function (an improvement of a function)

The sum of improved relative specifications is given by the equation (9).

$$\min Z=\sum_{i=1}^{N}\sum_{j=1}^{Si}(DF_{ij1}X_{ij2}+DF_{ij2}X_{ij2}+\cdots+DF_{ijsi}X_{ijsi}) \tag{9}$$

(2) Constraint 1 (the upper limit of the cost rise)

We represent the upper limit of raised cost for standardizing parts by a symbol T. The total rise of the manufacturing cost of all parts must be below that upper limit. This relation is shown in the equation (10).

$$T-\sum_{i=1}^{N}\sum_{j=1}^{Si}(D_{ij1}X_{ij1}+\cdots+D_{ijsi}X_{ijs}) >0 \tag{10}$$

(3) Constraint 2

Each part is allowed to select one part for the standardization. This relation is shown in the equation (11).

$$1-(X_{ij1}+X_{ij2}+\cdots+X_{ijsi})\geq 0 \qquad (i=1,\cdots,r) \;,\; (j=1,\cdots,S_i) \tag{11}$$

The above−mentioned standardization problem is represented by 0−1 integer programming problem. To solve the above problem we use the implicit enumeration, whose algorithm is simple and coding is easy.[3]

3. APPLICATION EXAMPLE

An example is studied to show the effectiveness of the proposed standardization method. The subjects are 16 kinds of personal computers. The relations between the cost and relative specifications of the subjects were checked. We set a target and attempted to minimize the degradation of the relative specifications.

3.1 Product structure trees of computers.

Fig.1 shows the product structure trees of sixteen computers. Examples of specifications of computers are CUP, memory capacity and so on. As these relative specifications are higher, the cost is higher.

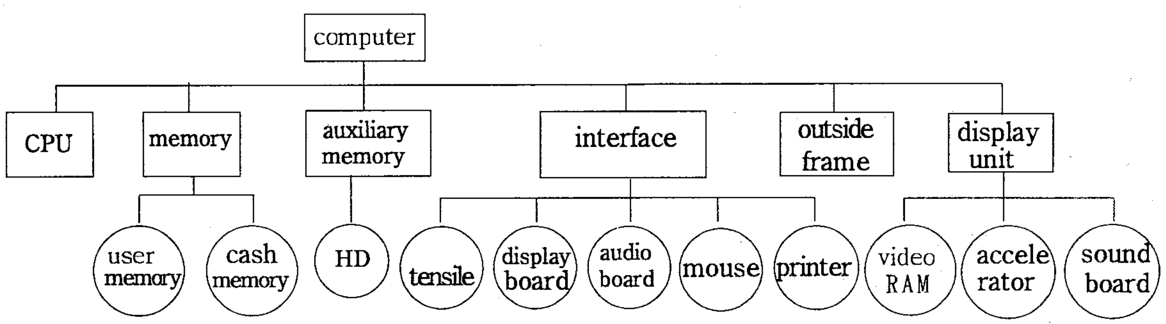

Fig 1. Product structure tree of a computer

The manufacturing cost of main memory and auxiliary memory (HD) is higher than that of the other parts. Main memory has been standardized and only two kinds of memories are used. We attempted to standardize the auxiliary memory. Nine kinds of auxiliary memory ($P_1, \cdots ,P_9$) are used.

3.2 Relative specifications

We considered four kinds of specifications, that is, memory capacity, seeking speed, cash memory size and the rotating speed of the auxiliary memory (HD). The relative specifications are given by the equation (1) for all the HDs. Table 5 shows the relative specifications and cost of HDs. From Table 5, the relations between the cost and relative specifications are shown in Figures from 2 to 4 below.

Table 5 Relative specification and cost of auxiliary memories

Product	Specification	Relative specification	Manufacturing cost	Product	Specification	Relative specification	Manufacturing cost
G1	memory capacity	0.062	74800	G6	memory capacity	0.382	75800
	seeking speed	1			seeking speed	0	
	cash memory	0.429			cash memory	0.429	
	rorating speed	0.567			rorating speed	0.567	
G2	memory capacity	0.152	84800	G7	memory capacity	0	99800
	seeking speed	1			seeking speed	0.333	
	cash memory	0.429			cash memory	0.143	
	rorating speed	0.567			rorating speed	0.329	
G3	memory capacity	0.382	118000	G8	memory capacity	0.17	148000
	seeking speed	0.667			seeking speed	0.333	
	cash memory	0.074			cash memory	0.143	
	rorating speed	0			rorating speed	0.329	
G4	memory capacity	1	198000	G9	memory capacity	0.191	41800
	seeking speed	0			seeking speed	0.667	
	cash memory	1			cash memory	0	
	rorating speed	1			rorating speed	0.567	
G5	memory capacity	0.152	53800				
	seeking speed	0.667					
	cash memory	0					
	rorating speed	0.334					

Fig.2 shows the relation between the cost and the memory capacity. Fig.3 shows the relation between the cost and the seeking speed. Fig.4 shows the relation between the cost and the cash memory size. Fig.5 shows the relation between the cost and the rotating speed of the discs. The total manufacturing cost of HDs were 895 thousand yen. Under these conditions, we set four target figures of cost reduction amount. The first target requires reducing 400 thousand yen in cost. The second 300 thousand yen, the third 200 thousand yen and the fourth 100 thousand yen.

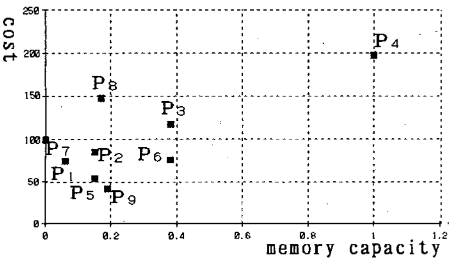

Fig.2 Relation between the cost and memory capacity

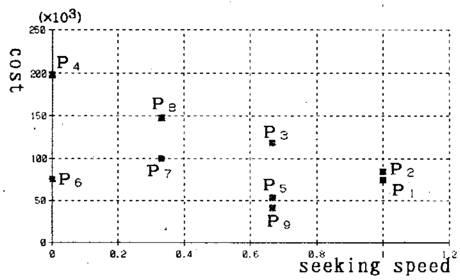

Fig.3 Relation between the cost and seeking speed

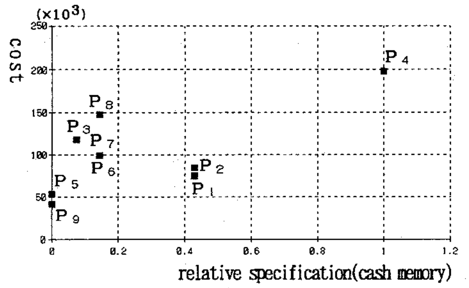

Fig. 4 Relation between the cost and cash memory size

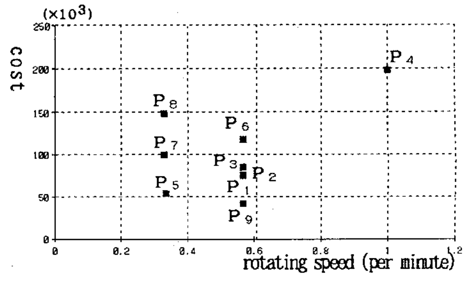

Fig.5 Relation between cost and rotating speed

From Table 5, we evaluated the expected reduced cost that is obtained by changing an HD to an other type. Expected amount of cost reduction is shown in the Table 6. Next, we evaluated the change of the relative specifications by the equation (4) for all the combinations of the HDs and showed it in Table 7.

Table 6 The table of cost reduction amount

	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	0	10	43	123	-21	1	25	73	-33
P2	-10	0	33	113	-31	-9	15	63	-43
P3	-43	-33	0	80	-64	-42	-18	30	-76
P4	-123	-113	-80	0	-144	-122	-98	-50	-156
P5	21	31	64	144	0	22	46	94	-12
P6	-1	9	42	122	-22	0	24	72	-34
P7	-25	-15	18	98	-46	-24	0	48	-58
P8	-73	-63	-30	50	-94	-72	-48	0	-106
P9	33	43	76	156	12	34	58	106	0

Table 7 The change of the relative specification by the standardization

	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	0	9	-37	94	-91	-68	-126	-109	-63
P2	-9	0	-46	85	-100	-77	-135	-118	-72
P3	37	46	0	131	-54	-31	-89	-72	-26
P4	-94	-85	-131	0	-185	-162	-220	-203	-157
P5	91	100	54	185	0	23	-35	-18	28
P6	68	77	31	162	-23	0	-58	-41	5
P7	126	135	89	220	35	58	0	17	63
P8	109	118	72	203	18	41	-17	0	46
P9	63	72	26	157	-28	-5	-63	-46	0

3.3 Modeling of the standardization for reducing the manufacturing cost

From Table 7, we set 81 variables of X_{ijq} as shown in Table 8. For example, variable X_3 represents a case where the part P_1 is changed to the part P_2. We considered four target figures of cost reduction amount: 400,000 yen, 300,000 yen, 200,000 yen and 100,000 yen. The entire 0−1 integer programming model for cutting the manufacturing cost more than 400,000 yen is represented as below.

Table 8 Variables

	P1	P2	P3	P4	P5	P6	P7	P8	P9
P1	X1	X2	X3	X4	X5	X6	X7	X8	X9
P2	X10	X11	X12	X13	X14	X15	X16	X17	X18
P3	X19	X20	X21	X22	X23	X24	X25	X26	X27
P4	X28	X29	X30	X31	X32	X33	X34	X35	X36
P5	X37	X38	X39	X40	X41	X42	X43	X44	X45
P6	X46	X47	X48	X49	X50	X51	X52	X53	X54
P7	X55	X56	X57	X58	X59	X60	X61	X62	X63
P8	X64	X65	X66	X67	X68	X69	X70	X71	X72
P9	X73	X74	X75	X76	X77	X78	X79	X80	X81

Object: Max

$$Z = 0X_1 + 9X_2 - 37X_3 + 94X_4 - 91X_5 - 68X_6 - 126X_7 - 109X_8 - 63X_9$$
$$- 9X_{10} + 0X_{11} - 46X_{12} + 85X_{13} - 100X_{14} - 77X_{15} - 135X_{16} - 118X_{17} - 72X_{18}$$
$$\vdots$$
$$+ 63X_{73} + 72X_{74} + 26X_{75} + 157X_{76} - 28X_{77} - 5X_{78} - 63X_{79} - 46X_{80} + 0X_{81}$$

Constraints: (1)

$$0X_1 + 10X_2 + 43X_3 + 123X_4 - 21X_5 + 1X_6 + 25X_7 + 73X_8 - 33X_9$$
$$- 10X_{10} + 0X_{11} + 33X_{12} + 113X_{13} - 31X_{14} - 9X_{15} + 15X_{16} + 63X_{17} - 43X_{18}$$
$$\vdots$$
$$+ 33X_{73} + 43X_{74} + 76X_{75} + 156X_{76} + 12X_{77} + 34X_{78} + 58X_{79} + 106X_{80} + 0X_{81} \geqq 400{,}000$$

(2) $1-(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9) \geqq 0$

$1-(X_{10} + X_{11} + X_{12} + X_{13} + X_{14} + X_{15} + X_{16} + X_{17} + X_{18}) \geqq 0$

:

$1-(X_{73} + X_{74} + X_{75} + X_{76} + X_{77} + X_{78} + X_{79} + X_{80} + X_{81}) \geqq 0$

Where, subject (1) shows that the reduced cost amount exceeds the target cost reduction amount. Subject (2) shows that one part is not able to be made common to more that two kinds of parts. We did not consider the maximum value XL_{ij} which degrades relative specification of parts.

3.4 The standardization results

We solved 0−1 integer programming problem and showed the result in Table 9. In order to reduce 400,000 yen in cost, it is necessary that P_3, P_4, P_5, P_7 and P_8 be standardized to the part that has a specification of P_9. Then degradation becomes the minimum (−0.46). The relative specification of P_4 recorded a sharp drop. Especially a relative specification of cash memory recorded a sharp drop.

Table 9 The standardization result

Amount of cost reduction ($\times 10^3$ yen)	Standardization	Change of relative specification
400	$P_3 \to P_9$, $P_4 \to P_9$, $P_5 \to P_9$ $P_7 \to P_9$, $P_8 \to P_9$	-0.46
300	$P_4 \to P_9$, $P_7 \to P_9$, $P_8 \to P_9$	-0.48
200	$P_4 \to P_9$, $P_8 \to P_2$	-0.39
100	$P_8 \to P_9$	+0.46

The total cost before a standardization = 895,000 (yen)

The combination of the standardized parts is shown in Table 9, corresponding to the other target figures of cost reduction amount, 300,000 yen, 200,000 yen and 100,000 yen. Table 6 shows that the relative specification was improved (+0.46) in contrast with the reduced cost when the target figure of cost reduction is 100,000 yen.

4. CONCLUSION

A part standardization method that considers the specifications of parts and the manufacturing cost is proposed.

(1) The relation between specification and the cost is evaluated.

(2) Parts are standardized based on their specification and manufacturing cost. Two methods are proposed for standardizing the parts. One method aims at cost reduction without causing any degradation of relative specifications of parts. The other method aims at satisfying the upper limit of cost and maximizing the relative specifications.

Reference

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