

# DEVELOPMENT OF AN ALGORITHM IMPROVING LABEL ARRANGEMENTS IN OFFSET PRINTING

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ABSTRACT. One of the most classic problems in the manufacturing industry is inventory processing. There is a way to effectively reduce inventory by changing the array of pieces on the printing plates in the offset printing. It is done by setting an acceptable upper limit for each plate, and by carrying out complete enumeration. This method drastically reduces the operating time of the algorithm. The advantage of this method is that it focuses on changing the arrangement of the pieces on the plates.

## 1. INTRODUCTION

A combination with repetition is the number of cases, where  $k$  elements are selected from different  $n$  elements allowing repetition [1]. It is indicated with the symbol  ${}_nH_k$  and the following is established.

$$(1.1) \quad {}_nH_k = {}_{n+k-1}C_k = \frac{(n+k-1)!}{(n-1)!k!}$$

For instance, the combination with repetition  ${}_2H_4$  to select four elements from among two elements A and B comprises the following five cases.

- (1) [A, A, A, A] : a list consisting of four A's
- (2) [A, A, A, B] : a list consisting of three A's and one B
- (3) [A, A, B, B] : a list consisting of two A's and two B's
- (4) [A, B, B, B] : a list consisting of one A and three B's
- (5) [B, B, B, B] : a list consisting of four B's

Among the above cases, if we want to obtain three A's and nine B's, we can choose [A, B, B, B]  $\times$  3. Also, we consider the following as another case.

$$(1.2) \quad [A, A, B, B] \times 1 + [A, B, B, B] \times 1 + [B, B, B, B] \times 1$$

In this case, we can get the three A's and nine B's. However, the former case seems to be a 'better' choice because there are three different lists in (1.2). Let us examine another case.

$$(1.3) \quad [A, A, A, A] \times 1 + [B, B, B, B] \times 3 - [A] \times 1 - [B] \times 3$$

[A, B, B, B]  $\times$  3 also seems to be a 'better' choice because there is no loss. Under the following conditions, [A, B, B, B]  $\times$  3 is the 'best' choice.

- (1) Minimize the number of lists.
- (2) Minimize the loss of lists.

Offset printing, also called offset lithography, or litho-offset in commercial printing, is a widely used printing technique in which the inked image on a printing plate is printed on a rubber cylinder and then transferred (i.e., offset) to paper or other

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28 material. The rubber cylinder gives great flexibility, permitting printing on wood,  
29 cloth, metal, leather, and rough paper (see Figure 1.1) [5].

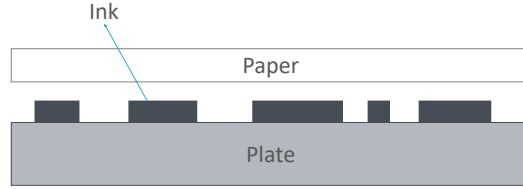


FIGURE 1.1. Offset Printing

30 Offset printing is one of the most common ways of creating printed materials.  
31 A few of its common applications include: newspapers, magazines, brochures, sta-  
32 tionery, and books. Compared to other printing methods, offset printing is best  
33 suited for economically producing large volumes of high quality prints in a manner  
34 that requires little maintenance [6]. To improve printing process, there were many  
35 researches in [2,3,7]. As another improvement, how to make the initial plates is an  
36 important issue. The above example shows what is the best arrangement in such  
37 printing method.

38 In the past, production was based on the ordering of products from companies  
39 and predictions of consumption. However, as the internet market has become pop-  
40 ular, the production systems have been altered by consumers. Now, many factories  
41 produce only products ordered by consumers.

42 World Komax is a company that produces labels using the offset printing. The  
43 labels refer to stickers containing bar-codes attached to garments or shoes as follows  
44 (see Figure 1.2). Each bar-code in the label contains fixed information such as  
45 product names and colors, and variable information such as the manufacturing  
46 date.



FIGURE 1.2. Sneaker Review : Nike Air Huarache

47 Since the program of World Komax is not suitable for small quantity batch pro-  
48 ductions, the number of label losses increased compared to the past.

49 Section 2 of this paper will describe the process of label printing using offsets.  
50 The modeling of the problem will be carried out in Section 3, and examples to help  
51 the understanding of the problem will be prepared in Section 4. The final results  
52 of the algorithm will be described in Section 5.

## 53 2. OFFSET LABEL PRINTING PROCESS

54 **2.1. Label printing process.** Before discussing the process of label printing, we  
55 define the following terms.

56 \* **Plate** : A printing plate for the offset printing (see Figure 2.1)

\* **Loss** : The number of labels printed in excess of the order-quantity

The offset label printing process is as follows. First, we receive orders from customers. The order includes many types of labels and order-quantities by type (see Figure 2.2). Thereafter, offset printing plates are made. Many types of labels are placed on each plate so that many labels are printed at once. After the plates are made, we produce more labels than order-quantities using each plate. Then, the sheets are cut into the label size. For the final process, the labels are collected by type.

**2.2. Major points for cost saving.** The constraints and major points that will be considered in this paper for cost saving are as follows. First, one type of label should be placed on only one plate. This is to prevent different types of labels from being mixed when collected by type after the printed sheets are cut. Meanwhile, the total number of labels placed on each plate is also constant because the sizes of individual plates are constant and the sizes of labels in one order are also constant. In addition, the number of plates should be as minimized as possible because plates are made using molds and the costs are high. Finally, the Loss should be minimized because overprinted labels cannot be used and should be entirely discarded.

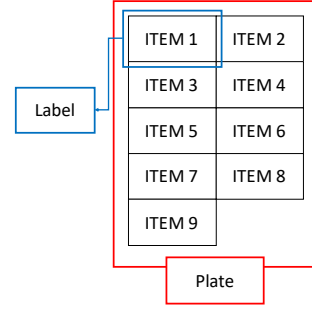


FIGURE 2.1. Plate and Label

**2.3. Sorting reports output program.** The production of plates and the use of printing paper incur costs. To reduce the costs, order details are input to output appropriate methods to place labels on the plate as sorting reports. The plate makers produce plates according to the instructions in the sorting reports (see Figure 2.2).

Since the existing sorting report output method was not suitable for small quantity batch production systems, the algorithm had to be improved. Therefore, this study was conducted to develop new algorithms suitable for small quantity batch production systems too.

### 3. MODELING AND FLOWCHART

To formulate our problem as a mathematical optimization problem, we first need to define our notation.

- Let  $I$  be a set of products.
- For each product  $i \in I$ , let  $b_i$  be the number of orders.
- Let  $\mathbf{b} = (b_i | i \in I)$  be a vector of order-quantities.
- $k$  is the total number of labels that can be placed in one Plate.
- $\pi$  is a partition of  $I$  such that  $1 \leq |P| \leq k$  for any  $P \in \pi$ .
- Let  $\Gamma_\pi$  be a set of matrix  $A \in \text{Mat}_{\pi \times I}(\mathbf{Z})$  satisfying the following:
  - For all  $(P, i) \in \pi \times I$ ,  $A_{P,i} \geq 0$ , and  $A_{P,i} = 0$  if and only if  $i \notin P$ .
  - For each  $P \in \pi$ ,  $\sum_{i \in P} A_{P,i} = k$ .

Using the above notation,

$$(3.1) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P,i}} \mid i \in P \right\} \right\rceil$$

is the printing number of Plate  $P$ , where  $\lceil \cdot \rceil$  means the ceiling. Assume that  $\alpha$  is the cost to produce one Plate, and  $\beta$  is the cost of the loss of one label. Then, our

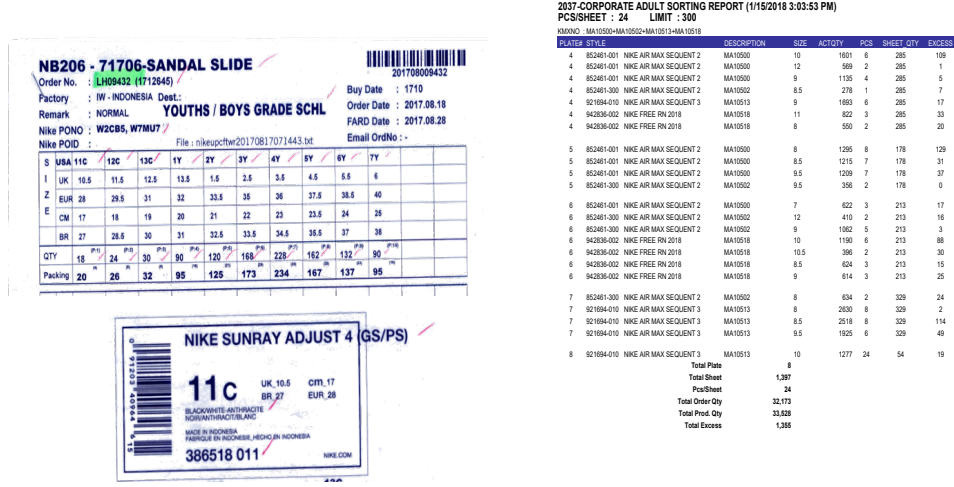


FIGURE 2.2. An Order Form(left) and a Sorting Report(right)  
 (Source: World Komax Co., Ltd.)

goal is to obtain the following

$$(3.2) \quad \min_{\pi} \{ \alpha |\pi| + \beta E_{A,b} | A \in \Gamma_{\pi} \}$$

where

$$(3.3) \quad E_{A,b} = \sum_{P \in \pi} \sum_{i \in I} \left( \left\lceil \max \left\{ \frac{b_i}{A_{P,i}} \mid i \in P \right\} \right\rceil \cdot A_{P,i} - b_i \right)$$

means the total number of losses of labels.

Naturally, the complete enumeration using combinations with repetition is the surest way. However, this method takes too much time. For instance, when  $n = 65$  and  $k = 24$ , the combination with repetition  ${}_{65}H_{24}$  comprises about  $2.36 \times 10^{21}$  cases. Then, the calculation takes more than 658 hours, that is, more than 27 days using a super computer that can calculate  $10^{15}$  partitions per second. Given that there are time constraints from the date of order receipts to the delivery date, this is a very long computation time.

In this algorithm, this problem was solved by introducing any positive integers as thresholds. Thresholds mean the allowed amount of losses occurring in each plate. Adopting a partition that does not exceed the threshold will dramatically reduce the time taken. Based on the foregoing, the flowchart of the algorithm can be set forth as follows (see Figure 3.1).

In Figure 3.1,  $z$  is the threshold and the others are explained in the notation above. This algorithm outputs matrix  $A = \bigoplus_P A_{P,i}$  containing the label of each product when  $I$  and  $\mathbf{b}$  have been input for  $z$ ,  $k$ ,  $num$ . One of the results of  $loop(k, z, num)$ ,  $P$  is the set of products that contains the Plate (see Figure 3.2). By removing  $P$  from  $I$ , each plate does not have the same product. The algorithm repeats until  $I$  is empty.

Meanwhile, in the case of the  $loop(k, z, num)$  function, the flowchart in Figure 3.2 should be followed. First, the  $Part(k, num)$  function finds partitions using the combination with repetition  ${}_{num}H_k$  which is indicated in the form of a list. We set the result as  $Part\_list$ . For example, let  $k = 6$  and  $num = 3$ , then  $Part\_list = Part(6, 3) = \{[4, 1, 1], [3, 2, 1], [2, 2, 2]\}$ .  $N$  is a printing number that is expressed in

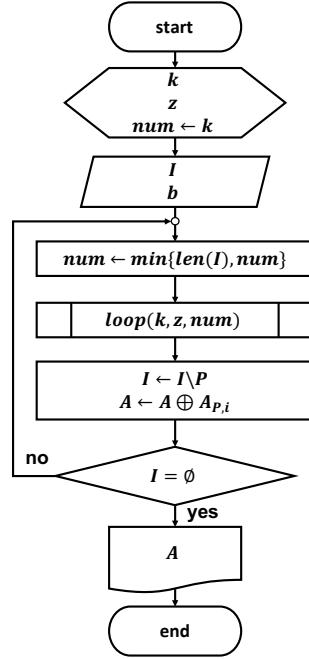
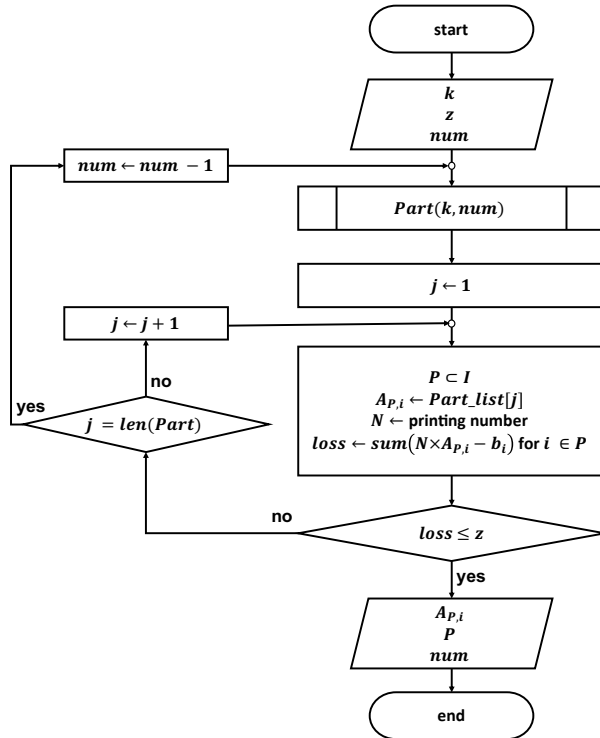


FIGURE 3.1. The Main Flowchart

FIGURE 3.2. The Flowchart of  $loop(k, z, num)$ 

128 (3.1). An appropriate  $P$  that has  $num$  pieces of products is selected from  $I$  and  
 129 the loss is obtained using  $Part\_list$  and the printing number.

130 If the loss exceeds the threshold  $z$ , another *Part\_list* will be selected and the  
 131 foregoing will be repeated while adjusting *num* until the threshold  $z$  is not exceeded.  
 132 As a result of this process,  $A_{P,i}$  whose loss does not exceed the threshold is obtained.

#### 133 4. EXAMPLES

134 This example was described to help the understanding of the problem. For the  
 135 next two examples, we assume that  $k$  is equal to 4.

136 **Example 4.1.** Assume that  $I = \{1, 2, 3\}$ , and  $\mathbf{b} = (50, 30, 20)$ .

137 We consider  $\pi = \{\{1, 2\}, \{3\}\}$ , a partition that matches  $\mathbf{b}$ . Without loss of  
 138 generality, assume that  $P_1 = \{1, 2\}, P_2 = \{3\}$ . Since  $k = 4$ , the matrix  $A$  can be  
 139 found as follows.

$$(4.1) \quad A = \begin{pmatrix} 2 & 2 & 0 \\ 0 & 0 & 4 \end{pmatrix}$$

140 In this case, the printing numbers (3.1) of  $P_1$  and  $P_2$  are as follows, respectively.

$$(4.2) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P_1,i}} \mid i \in P_1 \right\} \right\rceil = \left\lceil \max \left\{ \frac{50}{2}, \frac{30}{2} \right\} \right\rceil = 25$$

141 and

$$(4.3) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P_2,i}} \mid i \in P_2 \right\} \right\rceil = \left\lceil \max \left\{ \frac{20}{4} \right\} \right\rceil = 5.$$

142 We can see Figure 4.1 for more details.

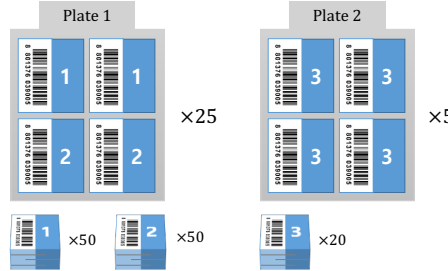


FIGURE 4.1

143 It can be seen that the total number of Loss  $E_{A,\mathbf{b}}$  is 20.

144 Now, we consider a new partition  $\pi = \{\{1, 2, 3\}\}$ . In this case,  $A = \begin{pmatrix} 2 & 1 & 1 \\ 1 & 2 & 2 \end{pmatrix}$ ,  
 145 and printing number (3.1) is

$$(4.4) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P,i}} \mid i \in P \right\} \right\rceil = \left\lceil \max \left\{ \frac{50}{2}, \frac{30}{1}, \frac{20}{1} \right\} \right\rceil = 30.$$

146 In addition, it can be easily seen that the total number of Loss  $E_{A,\mathbf{b}}$  is 20 (see  
 147 Figure 4.2). The array shown in Figure 4.2 is more efficient since its Loss is the  
 148 same but its number of plates is smaller.

149 **Example 4.2.** Assume that  $I = \{1, 2\}$ , and  $\mathbf{b} = (50, 20)$ .

150 We consider  $\pi = \{\{1, 2\}\}$ , a partition that matches  $\mathbf{b}$ . Since  $k = 4$ , the matrix  
 151  $A = \begin{pmatrix} 2 & 2 \\ 2 & 2 \end{pmatrix}$ , and the printing number (3.1) is

$$(4.5) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P,i}} \mid i \in P \right\} \right\rceil = \left\lceil \max \left\{ \frac{50}{2}, \frac{20}{2} \right\} \right\rceil = 25.$$

152 The total number of Loss  $E_{A,\mathbf{b}}$  is 30 (see Figure 4.3).

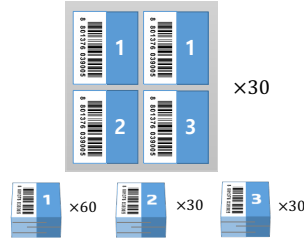


FIGURE 4.2



FIGURE 4.3

153 For the same partition  $\pi$ , matrix  $A = \begin{pmatrix} 3 & 1 \end{pmatrix}$  can be considered. In this case,  
 154 the printing number (3.1) is

$$(4.6) \quad \left\lceil \max \left\{ \frac{b_i}{A_{P,i}} \mid i \in P \right\} \right\rceil = \left\lceil \max \left\{ \frac{50}{3}, \frac{20}{1} \right\} \right\rceil = 20$$

155 and the total number of Loss  $E_{A,b}$  is 10 (see Figure 4.4). The array shown in Figure  
 156 4.4 is more efficient because its number of plates is the same but fewer losses occur.

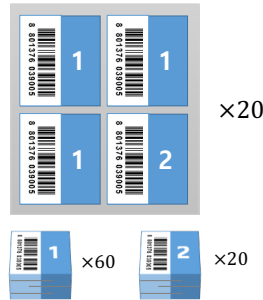


FIGURE 4.4

157

158 If there are too many products and large order-quantities, it requires a lot of  
 159 iteration. Now, we consider a real problem of World Komax. In this case,  $k = 18$ ,  
 160  $\alpha = 300$ ,  $\beta = 1$ . Table 4.1 is an actual sorting report of an order from World  
 161 Komax.

162 As we can see from Table 4.1, there are 14 products and the largest order-quantity  
 163 is 1059. It uses 3 plates and total Loss is 611. Total cost is 1511.

164 **Example 4.3.** We obtain another partition of the sorting report using our algo-  
 165 rithms. Table 4.2 shows this result.

TABLE 4.1. the sorting report of World Komax

Plate	product	order-quantity	psc	printing-number	production	Loss
1	1	59	2	32	64	5
	2	156	5		160	4
	3	9	1		32	23
	4	162	6		192	30
	5	102	4		128	26
2	6	1059	5	228	1140	81
	7	886	4		912	26
	8	228	1		228	0
	9	832	4		912	80
	10	862	4		912	50
3	11	532	4	133	532	0
	12	532	5		665	133
	13	482	4		532	50
	14	582	5		665	103

TABLE 4.2. the result of our algorithm

Plate	product	order-quantity	psc	printing-number	production	Loss
1	7	886	5	178	890	4
	10	862	5		890	28
	11	532	3		534	2
	12	532	3		534	2
	4	162	1		178	16
	2	156	1		178	22
2	6	1059	9	118	1062	3
	14	562	5		590	28
	8	228	2		236	8
	5	102	1		118	16
	1	59	1		118	59
3	9	832	11	76	836	4
	13	482	7		532	50
4	3	9	18	1	18	9

The matrix  $A$  can be found as follows.

$$\begin{array}{c}
 \text{column index} \\
 7 \quad 10 \quad 11 \quad 12 \quad 4 \quad 2 \quad 6 \quad 14 \quad 8 \quad 5 \quad 1 \quad 9 \quad 13 \quad 3 \\
 A = \begin{pmatrix} 5 & 5 & 3 & 3 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 9 & 5 & 2 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 11 & 7 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 \end{pmatrix}
 \end{array}$$

166 The total Loss  $E_{A,b}$  is 251. So, total cost is  $\alpha|\pi| + \beta E_{A,b} = 300 \times 5 + 1 \times 251 = 1451$ .

167 We use one more Plate, but the total cost is reduced by 60.

## 168 5. RESULT

169 Each sorting report includes the number of losses corresponding to one plate.

170 Using this, the total cost can be calculated by replacing each plate with loss. We



171 used 82 sorting report samples. The total cost was reduced by a minimum of  
 172 -6.85%(sample no. 15) to a maximum of 27.5%(sample no. 74) (see Figure 5.1).

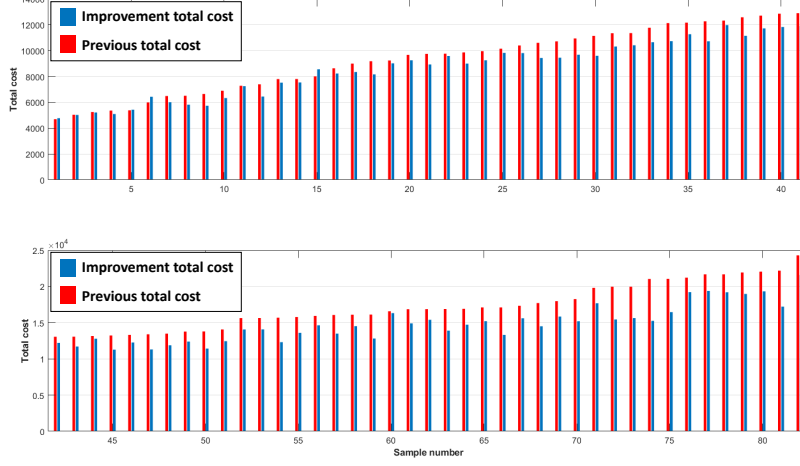


FIGURE 5.1. Comparing the Results

173 We used the *paired t-test* [8] to verify the efficiency of the algorithm. The paired  
 174 t-test is one of the two sample t-tests, and it is a test that verifies whether the two  
 175 groups are different. The two populations are as follows.

- 176 • population1: total cost before applying the algorithm
- 177 • population2: total cost after applying the algorithm
- 178 • sample1: sample of 82 items from population1
- 179 • sample2: sample of 82 items from population2

180 In order to proceed with the two-sample t-test, the two groups have to satisfy  
 181 normality and homoscedasticity. We choose 82 sample data from the two popula-  
 182 tions, which can satisfy normality by the *central limit theorem* [4]. In addition, we  
 183 identified the homoscedasticity of the two samples through the *var.test* of R. R is  
 184 a programming language and free software environment for statistical computing  
 185 and graphic.

186 The null hypothesis ( $H_0$ ) of *var.test* is that ‘the variances of the two groups are  
 187 equal’, and the alternative hypothesis ( $H_1$ ) is that ‘the variances of the two groups  
 188 are different’. If the *p*-value is below the significance level, the null hypothesis  
 189 ( $H_0$ ) will be rejected and if the *p*-value is not lower than the significance level,  
 190 the alternative hypothesis ( $H_1$ ) will be rejected. The result of *var.test* with the  
 191 significance level to 0.05 is as follows (see Figure 5.2).

```
> var.test(sample1,sample2)

F test to compare two variances

data: sample1 and sample2
F = 1.5552, num df = 81, denom df = 81, p-value = 0.04847
alternative hypothesis: true ratio of variances is not equal to 1
95 percent confidence interval:
 1.002998 2.411501
sample estimates:
ratio of variances
 1.555227
```

FIGURE 5.2. *var.test* of R

192 Since the *p*-value is not lower than the significance level(0.05), the alternative  
 193 hypothesis ( $H_1$ ) is rejected and the null hypothesis ( $H_0$ ) is accepted. We say that  
 194 the variances of the two groups can be equal.

195 Since the two groups satisfy normality and homoscedasticity, we verified whether  
 196 the difference between the two groups is significant through paired t-test. In this  
 197 test, the null hypothesis ( $H_0$ ) is ‘the total cost will be the same after applying the  
 198 algorithm.’ and the alternative hypothesis ( $H_1$ ) is ‘the total cost will be reduced  
 199 after applying algorithm.’ The result of the paired t-test with the significance level  
 200 to 0.05 is as follows (see Figure 5.3).

```
> t.test(sample1,sample2, paired=TRUE)

Paired t-test

data: sample1 and sample2
t = 10.766, df = 81, p-value < 2.2e-16
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 1240.884 1803.531
sample estimates:
mean of the differences
      1522.207
```

FIGURE 5.3. t.test of R

201 Since the  $p$ -value is below the significance level(0.05), the null hypothesis ( $H_0$ ) is  
 202 rejected and the alternative hypothesis ( $H_1$ ) is accepted. We say that the difference  
 203 between the two groups can be significant.

204 Finally, we check the efficiency over the number of products which is the size of  
 205  $I$  (cf. Section 3). We see that the efficiency increases as the number of products  
 206 increases in Figure 5.4. For each of the 82 samples, we calculated the efficiency as  
 207 the following formula.

$$(5.1) \quad \text{Efficiency} = \left[ 1 - \frac{\text{Improvement Total Cost}}{\text{Previous Total Cost}} \right] \times 100$$

208 The result of the linear fitting shows that the efficiency and the number of products  
 209 have a positive correlation. Thus, we see that the improved algorithms have better  
 210 results in many products. This suggests that the algorithm fits well into small  
 211 quantity batch productions.

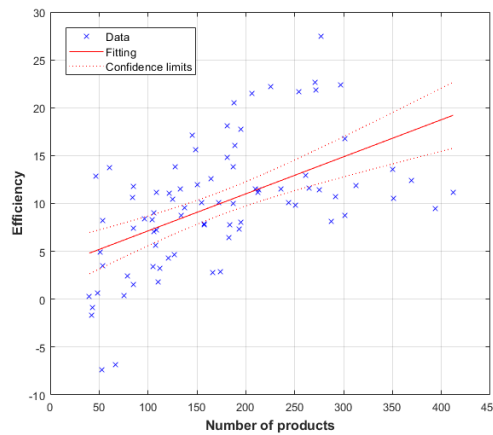


FIGURE 5.4. The linear fitting for the efficiency over the number of products

**Notice.** Please note that the detailed idea of the algorithm cannot be described for company confidentiality reasons.

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