Optimization Study of Laundry Cleaning Based on K-means Clustering and Simulated Annealing Algorithm

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Abstract. Laundry is something people do every day, clothing cleaning effect and cleaning time, the number of times of cleaning, the amount of clothing detergent, water consumption and power consumption and other factors are closely related, whether in the daily cleaning, or the organization's business process, the choice of cleaning methods and the control of the cleaning cost are crucial. In order to find the optimal cleaning method, as well as the best cleaning solution, this paper carries out a study on laundry cleaning optimization based on nonlinear programming. Firstly, a cleaning method optimization method based on dynamic programming is proposed to get the optimal solution about the number of washing times and the amount of water used in each washing, and then, a cleaning cost optimization method based on simulated annealing is proposed to get the optimal cleaning solution that saves cost and has excellent cleaning effect. In this paper, ten different detergents are used to conduct experimental analysis on 36 pieces of clothing containing eight pollutants.

Keywords: K-means clustering; dynamic programming; simulated annealing algorithm; SVD dimensionality reduction.

1. Introduction

Laundry cleaning is one of the most common activities in daily life. Products used for clothes washing have gone through a long process of development from the earliest natural products such as saponin plants to today's widely used clothes cleaners. Washing methods have also evolved from manual scrubbing to today's smart machine washing. However, the impact of cleaning time, number of washes, amount of laundry detergent used, water consumption, and electricity consumption on the effectiveness of laundry cleaning needs to be considered, both in daily cleaning and in the operation of the organisation. The choice of cleaning method and the control of cleaning costs are crucial to family life, as well as to the operation of the organisation.

In order to find the best laundry way and the best laundry scheme, this paper carries out the research of laundry cleaning optimization based on nonlinear programming. Firstly, an optimization method of laundry ways based on dynamic programming is proposed to obtain the optimal solution of washing times and water consumption per washing, so as to obtain the optimal laundry way. Next, this paper proposes a laundry costs optimization method based on simulated annealing, in order to obtain the best cleaning scheme with both cost saving and excellent cleaning effect [1].

2. Data processing

In this paper, the characteristics of the dataset are preliminarily analyzed with the help of MATLAB software, and then the data are cleaned and normalized, so as to lay the foundation for subsequent research.

2.1. Data cleaning

Through data identification, no missing values were found in the dataset. Therefore, this paper uses boxplot to test outliers on the dataset, and the results are shown in Fig. 1.
According to the box plot, the points beyond the error line are regarded as abnormal points, and then the average of the number of pollutants is taken for supplement.

2.2. Normalization processing

Since the content of pollutants on clothing and the unit of measurement of water are different, in order to improve the comparability and interpretability of data, this paper uses the extreme value processing method to normalize the data, and the calculation process is as follows:

\[ x_{\text{normalization}} = \frac{x - \min}{x - \max} \]  

(1)

3. Model building and solution

3.1. An optimisation method for laundry ways based on dynamic programming

According to the degree of dirt, different cleaning ways need to be adopted. The specific performance is that the lightly stained clothes can be cleaned only once or twice, and with the increase of the degree of dirt, the number of washing cycles should also increase to clean up the dirt on the clothes. Since the washing effect is the same every time, the process of cyclic cleaning clothes is actually a dynamic recursive process, which can be solved by nonlinear programming model. This paper assumes constraint is that the proportion of contaminants remaining on the laundry after numerous washes to the contaminants on the laundry at the beginning is \( \epsilon \), with the stipulation that \( \epsilon = 2.2204 \times 10^{-16} \). The objective function is the number of washing cycles and the corresponding water consumption [2].

Since the content of contaminants in clothing is related to the number of washes, there is a special relationship between the two. It can be expressed in two ways. One way is the constant moisture content of the clothing after dehydration and the amount of water added during the first wash, which is related to the content of pollutants in the clothing. Another way is the relationship between the decontamination efficiency of the detergent during washing and the solubility of the pollutant, which matches the content of the residual pollutant in the clothing.

The amount of contaminants left on the garment after the \( n \) times of washing is:

\[ C_n = \frac{W^n}{b_1 \times \prod_{i=2}^{n} (b_i + W)} \times C_0 \]  

(2)

\[ \lambda_1 = \frac{W^n}{b_1 \times \prod_{i=2}^{n} (b_i + W)} \]  

(3)

Through (2) and (3), the following results can be obtained:

\[ C_n = \lambda_1 C_0 \]  

(4)

\[ 0 < \lambda_1 < 1 \]  

(5)
If a garment with contamination content of \( C_0 \) is put into the washing machine, the amount of contamination still remaining on the garment is \( C_1 \), and if a detergent with a decontamination rate of \( \tau \) is added, the amount of contamination still remaining on the garment after washing is:

\[
C_1 = (1 - \tau)(1 - a_1)C_0
\]

Similarly:

\[
\begin{align*}
C_2 &= (1 - \tau)(1 - a_2)C_1 \\
C_3 &= (1 - \tau)(1 - a_3)C_2 \\
&\vdots \\
C_n &= (1 - \tau)(1 - a_n)C_{n-1}
\end{align*}
\]

According to the groups of formula (5), the intensive form is:

\[
C_n = [(1 - \tau)^n \times \prod_{i=1}^{n} (1 - a_i)] \times C_0
\]

\[
\lambda_2 = (1 - \tau)^n \times \prod_{i=1}^{n} (1 - a_i)
\]

It can simply write it as:

\[
C_n = \lambda_2 C_0
\]

And \( \lambda_2 \) is also called the washability, which expresses the formula of washability differently. Therefore, we can obtain it \( \lambda_1 = \lambda_2 \), which means that:

\[
\frac{W^n}{b_1 \times \prod_{i=2}^{n} (b_i + W)} = (1 - \tau)^n \times \prod_{i=1}^{n} (1 - a_i)
\]

\[
(1 - \tau)^n \times \prod_{i=1}^{n} (1 - a_i) \leq \frac{1}{1000}
\]

It can be solved by nonlinear programming model. The 10 different detergents were used to wash 8 stains on each piece of clothing separately, and the results are shown in Fig. 2.

Fig. 2 With no restriction of the number of laundering through 10 sorts of detergents

The dehydration rate could be calculated as:

\[
Water\% = \frac{W_i - W_{i-1}}{W_{i-1}} \times 100\%
\]

Simplifying the above equation to an intensive form, so it yields the following result:

\[
C_n = \frac{\prod_{i=1}^{n} W_i}{b_1 \times \prod_{i=2}^{n} (b_i + W_{i-1})} \times C_0
\]

Since it is optimal to keep the dehydration rate around 115%, it obtains:

\[
W_i = 2.15W_{i-1}
\]
\[ W_r = 2.15^{n-1}W_1 \] (16)

\[ \frac{\prod_{i=1}^{n} W_i}{b_1 \times \prod_{i=2}^{n} (b_1 + W_{i-1})} \leq \epsilon \] (17)

The results are shown in Table 1.

**Table 1.** Results display table

<table>
<thead>
<tr>
<th>N</th>
<th>Result</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>(1.0433 \times 10^{41}W_1^2 = 2.4643 \times 10^{15}W_1 + 2.624 \times 10^5 b_{33})</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>(1.1146 \times 10^{41}W_1^2 = 5.6956 \times 10^{15}W_1 + 1.311 \times 10^5 b_{33})</td>
<td>0</td>
</tr>
<tr>
<td>36</td>
<td>(4.3005 \times 10^{43}W_1^2 = 2.2111 \times 10^{16}W_1 + 5.120 \times 10^5 b_{36})</td>
<td>0</td>
</tr>
<tr>
<td>37</td>
<td>(3.1807 \times 10^{43}W_1^2 = 7.6063 \times 10^{15}W_1 + 8.192 \times 10^3 b_{37})</td>
<td>0</td>
</tr>
<tr>
<td>38</td>
<td>(7.3513 \times 10^{45}W_1^2 = 8.1768 \times 10^{15}W_1 + 4.096 \times 10^3 b_{38})</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>(1.9635 \times 10^{44}W_1^2 = 4.7247 \times 10^{15}W_1 + 5.120 \times 10^2 b_{30})</td>
<td>0</td>
</tr>
<tr>
<td>43</td>
<td>(1.2121 \times 10^{45}W_1^2 = 2.9347 \times 10^{15}W_1 + 3.200 \times 10^2 b_{43})</td>
<td>0</td>
</tr>
<tr>
<td>44</td>
<td>(7.0037 \times 10^{46}W_1^2 = 7.8870 \times 10^{14}W_1 + 4.000 \times 10^0 b_{44})</td>
<td>0</td>
</tr>
<tr>
<td>47</td>
<td>(1.7294 \times 10^{47}W_1^2 = 1.9596 \times 10^{14}W_1 + 1.000 \times 10^0 b_{47})</td>
<td>0</td>
</tr>
</tbody>
</table>

The results showed that little extra water was needed for more than 30 washes with different detergents. This means that the clothing has been cleaned to a certain standard. This result is almost identical to the one shown in Fig. 1.

### 3.2. An optimisation method for laundry costs based on simulated annealing

This paper collected the relevant data of the content of 8 pollutants in 36 pieces of clothing, as well as the relevant data of the unit price of 10 common detergents on the market and their solubility to pollutants. According to the different cleaning effects of 10 detergents on clothes with different degrees of dirt, the optimal cleaning scheme to balance the cleaning cost and cleaning effect was sought. The decision variables set in this paper are the price of each detergent and the solubility of different detergents to pollutants on different clothes. An optimization model with the objective function of minimum cleaning cost is established. Because there are too many feasible solutions, the operation time of traditional algorithm is too long. Therefore, this paper first uses SVD dimensionality reduction and K-means clustering to obtain the quantity and type of clothes that can be mixed for reduction and K-means means, and the calculation process is as follows:

\[ A = U \sum V^T \] (18)

According to the contour coefficient and cluster number, the 36 pieces of clothing are divided into three categories using K-means, and the calculation process is as follows:

\[ SSE = \sum_{j=1}^{K} \sum_{x \in C_j} (x - m_j)^2 \] (19)
For each sample point, its distance from each particle is calculated and assigned to the nearest cluster. In this paper, the Euclidean distance is taken as the distance function, and its calculation process is as follows:

$$\text{Dis} \ c e((x_1, y_1), (x_2, y_2)) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$  \hspace{1cm} (20)

The results obtained by Euclidean distance and K-means cluster analysis are shown in Fig. 3.

Fig. 3 The cluster analysis of Fig

The range of pollutants is shown in Fig. 4, from which we can see the range and average of the three groups of pollutants. The clothing in the first group was 1.8, 3, 3.8, 3.7, 3.7, 1.6, 1.8, 1.8, 3.2, 3. The second group was 3.92, 1.83, 1.3, 1.54, 2.77, 4.08, 2.08, 2.69, 2.08, 1.77; The third group was 5.57, 4.71, 2.71, 2.29, 3.57, 1.71, 1.14, 0.86. However, since the number of the first group of clothes is 17 pieces, more than 10 pieces, so it should be cleaned in two batches.

Fig. 4 Pollutant range diagram

Next, the objective function is set as the minimum cleaning cost, and the constraint is set as (1) the number of washing machines should not exceed 10. (2) When the last washing, the pollutant content shall not exceed one thousandth of the original pollutant. (3) The water charge for each wash is 3.8 yuan.

$$\text{Minimize } Z = \sum_{i=1}^{10} d[i] \cdot x[i] + w \cdot v \cdot \sum_{i=1}^{10} x[i]$$ \hspace{1cm} (21)

Constraints are:

$$S.T \left\{ \begin{array}{l} p[j] \prod_{i=1}^{10} (1 - c[i, j]^x[i]) < 0.001p[j]j = 1,2,\ldots,8 \quad w = 3.8 \quad 0 < n < 10 \end{array} \right.$$  \hspace{1cm} (22)

Calculate the objective function difference value. The randomly obtained solution $W'$ and current solution $W$, the difference between the two benefits is denoted as $f$. 
Then, establish probability functions that accept new solutions to prevent falling into local optimality.

\[
P = \begin{cases} 
1, & \Delta f < 0 \\
\exp \left( -\frac{\Delta f}{T_i} \right), & \Delta f \geq 0
\end{cases}
\]

The resulting model results are shown in Fig. 5.

**Fig. 5** Cleaning situation of the first group of clothes

The minimum cleaning cost of the first group of clothes is 3.7380 yuan, a total of 8 cycles of cleaning.

The detergent used for each cleaning is shown in Table 2.

<table>
<thead>
<tr>
<th>The n time</th>
<th>The detergent used</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first time</td>
<td>Detergent5</td>
</tr>
<tr>
<td>The second time</td>
<td>Detergent5</td>
</tr>
<tr>
<td>The third time</td>
<td>Detergent1</td>
</tr>
<tr>
<td>The fourth time</td>
<td>Detergent4</td>
</tr>
<tr>
<td>The fifth time</td>
<td>Detergent4</td>
</tr>
<tr>
<td>The sixth time</td>
<td>Detergent8</td>
</tr>
<tr>
<td>The seventh time</td>
<td>Detergent10</td>
</tr>
<tr>
<td>The eighth time</td>
<td>Detergent3</td>
</tr>
</tbody>
</table>

The cleaning cost of the second group of clothes and the use of detergent are shown in Fig. 6.

**Fig. 6** Cleaning situation of the second group of clothes

The minimum cleaning cost of the second group of clothes is 3.5275 yuan, a total of 8 cycles of cleaning.

The detergent used for each cleaning is shown in Table 3.

**Table 3.** Scheme of detergent use
The cleaning cost of the third group of clothes and the use of detergent are shown in Fig. 7. The minimum cleaning cost of the third group of clothes is 3.5153 yuan, a total of 8 cycles of cleaning.

The detergent used for each cleaning is shown in Table 4.

<table>
<thead>
<tr>
<th>The (n)th time</th>
<th>The detergent used</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first time</td>
<td>Detergent7</td>
</tr>
<tr>
<td>The second time</td>
<td>Detergent5</td>
</tr>
<tr>
<td>The third time</td>
<td>Detergent2</td>
</tr>
<tr>
<td>The fourth time</td>
<td>Detergent8</td>
</tr>
<tr>
<td>The fifth time</td>
<td>Detergent8</td>
</tr>
<tr>
<td>The sixth time</td>
<td>Detergent3</td>
</tr>
<tr>
<td>The seventh time</td>
<td>Detergent5</td>
</tr>
<tr>
<td>The eighth time</td>
<td>Detergent3</td>
</tr>
</tbody>
</table>

**Fig. 7 Cleaning situation of the third group of clothes**

To sum up, the cleaning cost of all the clothes is 14.5188 yuan.

### 4. Summary

Laundry cleaning is one of the most common activities in daily life. The cleaning effect of clothes is closely related to the cleaning time, cleaning times, the amount of laundry detergent, water consumption and power consumption, etc., whether it is in daily cleaning, or in the operation process of the organization, the choice of cleaning methods and the control of cleaning costs are crucial. In order to find the best cleaning method and the best cleaning scheme, this paper carried out the research of laundry cleaning optimization based on nonlinear programming. Firstly, an optimization method of cleaning way based on dynamic programming is proposed. The cyclic cleaning process is regarded as a dynamic recursive process, and the optimal solution of washing times and water consumption per washing is obtained by nonlinear programming model. Then, an optimization method of cleaning cost based on simulated annealing is proposed. Firstly, SVD reduction and K-means clustering are
used to classify clothes reasonably, and then simulated annealing algorithm is used to obtain the best cleaning scheme which not only saves cost but also has excellent cleaning effect [6].

In this paper, although some progress has been made in the research of laundry cleaning optimization based on nonlinear programming, there are still some shortcomings, which will be improved in the follow-up research. First of all, due to time constraints, the model proposed in this paper does not consider factors such as the volume and surface area of clothing. In addition, in real life, the cleanliness of clothing and the amount of dirt adhesion cannot be accurately measured. In the future work, the factors affecting the cleaning effect of clothing will be considered as fully as possible, and at the same time, we will try to put forward a more practical quantitative method of clothing cleanliness and dirt adhesion.

References


