**Study on Pallet of Tobacco Industry Performance Degradation Detection Model**

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**Abstracts.** In this paper, we first introduce the background of pallet using in tobacco industry and sharing. The establishment of sharing system usually needs set of perfect detection index system to evaluate pallets. However, pallets cannot be repaired, the performance will only gradually decline until lose effectiveness. Currently, in china, almost all kinds of standards for pallets are access standards, and set parameters what the new pallet needs to follow, but lack of standards of pallets-out based on actual application environment. In this paper, we establish deterioration model based on the theory of Reliability Mathematics and data accumulated over the years of China Tobacco Zhejiang Industrial Co., Ltd. Eventually we calculate the reliability change – point to compensate for this deletion.

**Introduction**

The modern logistics development of tobacco industry can be divided into three phases. The standard constructing phase is from 2003 to 2006, and the focus of this phase is internal logistics in the enterprises, especially the problem of how to regulate the construction of tobacco logistics distribution center. The overall promoting phase is from 2007 to 2009, and the focus is logistics at the provincial scale, especially the problem on how to co-ordinate the management of logistics at the provincial level and the construction between the industry and the commerce. After 2010, tobacco logistics went into a comprehensive upgrading phase, and the gravity of the work has shifted to the logistics construction, particularly the problem on how to develop tobacco logistics in a comprehensive, healthy and innovative way.

The entire-pallet transport of tobacco arises from the continuous exploration of integrated management and collaborative construction of logistics in industrial and commercial enterprises (Yong Sheng, 2014) by China Tobacco Zhejiang Industrial Co., Ltd. and it is one of the methods with the characteristic features of China Tobacco Zhejiang Industrial Co., Ltd. In logistics services. Firstly, the company constructs the model of Stock-to-Sales Ratio in order to real-timely master the inventory of commercial customers and predict the replenishment point according to pin number of days as well as safety stock, thereby triggering the sales logistics. Secondly, to achieve lean logistics and reduce inventory costs, the company builds JIT Logistics for the purpose of direct sales of goods and making a commitment with regard to the exact arrival time, thus putting forward a higher requirement on timely production preparation. Finally, the companies design the entire-pallet transport system based on RFID and install the relevant equipment and software for commercial enterprises for free in the context of No.1 engineering, so as to meet the rapid response of goods out of storage for industrial enterprises and timely collection, sorting, sales for commercial enterprises. As a result, the ‘efficient, flexible and safe’ brand system of logistics service can be truly realized. After the application of pallet transport, the pallet as a logistics unit would be used throughout the process of production, transportation, storage and sales of tobacco, thereby becoming the core of the tobacco supply chain operation.
Flat pallets in tobacco logistics

The key to the logistics pallet in sharing is the standardization of pallet. The State Tobacco Monopoly Bureau published ‘General flat pallets for tobacco industry transport’ (State Tobacco Monopoly Bureau, 2007) (YC/T 215-2007), and authorized to implement from May 1, 2007. The standard provides for the style of the pallet: the pallet with grid or dense slab in the top and plain type in the bottom can be used in one side and from four directions. It is suitable for forklift trucks, pallet trucks, automatic overhead warehouse and its auxiliary equipment, besides it can be put on the shelf or flat ground. (Fig. 1)

In addition, the standard (215-2007 YC/T) stipulates the main dimensions, tolerances, materials, performance, appearance, etc.. The wooden pallets generally are composed of fir, pine, iron and so on; while the plastic pallets are made of high-density polyethylene (HDPE), polypropylene (PP) and son on. In daily operation, wooden pallets are generally used in storage and handling of raw materials such as tobacco and auxiliary materials, etc., while plastic pallets are mostly used in finished cigarette logistics. In a word, the wooden pallet is generally used in the production process, while the plastic one is universally used in production, logistics and sales. This paper deals with the plastic pallets which are in large consumption and have high obsolescence rates.

Basic reliability theory

The reliability theory (Jinhua Gao et al., 2006) regards the life-span characteristic of products as the main research object, combining the quantitative analysis, and has a strict theory of mathematical definitions and methods. The mathematical models in solving problems on reliability can be divided into two categories: probabilistic model and statistical model. The probabilistic model means deducing the reliability index of product lifetime according to the information about the structure of the product, the life distribution of the components, and the distribution of the repair time; while the the statistical model means estimating and testing the lifetime of components or products according to data observation.

A non-negative random variable \( X \) is usually said to describe the lifetime of a product, and has the corresponding distribution function \( F(t) \) as

\[
F(t) = P\{X \leq t\}, t \geq 0
\]

(1)

where \( F(t) \) is the probability of a product in effectiveness before time \( t \), in other words, the
The probability of the product losing effectiveness for the time $t$ can be written as

$$ R(t) = P\{X > t\} = 1 - F(t) = \overline{F}(t) \quad (2) $$

Typically, the probability of the product in efficacy $R(t)$ in time interval $[0, t]$ is called the reliability of the product.

The main reliability index of the product beyond repair is MTTF (Mean Time to Failure), and its function is given by

$$ EX = \int_0^\infty t dF(t) \quad (3) $$

Suppose now the product begins to work at time $t = 0$, and $X$ represents the lifetime, then the proceeding of the product operation is demonstrated in Fig.2. It turns out that the product will stay in failure state once the product is ineffective and beyond repair.

Figure 2. Proceeding of non-repairable products.

Suppose the lifetime of a product is non-negative continuous random variable $X$, involving the distribution function $F(t)$ and the density function $f(t)$.

$$ r(t) = \frac{f(t)}{F(t)}, \quad t \in \{t : F(t) < 1\} $$

Here, we define $r(t)$ as a failure rate of random variable $X$. In terms of engineering applications, the failure rate is the ratio of the probability that failures occur per unit time when the product works to a certain moment. The typical failure rate function like a bathtub shape in Fig.3, is often called the bathtub curve.

As shown in Fig.3, the trend of $r(t)$ is decreasing before $I$, i.e. a early failure period when we can screen unaccepted products through the quality testing; between $I$ and $II$, $r(t)$ maintains a constant, i.e. a random failure period. It is the best period of the product's normal work; after $II$, the trend of $r(t)$ is rising, i.e. a wear time period when the product performance is gradually deteriorating due to aging, fatigue, wear and other reasons, so actions such as maintaining or replacing should be taken to maintain the normal operation of the product.
Deterioration Model

According to the standard of pallets in tobacco logistics and characteristics as well as requirements of finished product logistics, the materials of pallets are made of plastics, which has the advantages of strong plasticity, durability and adaptability to environmental changes and stable physical, chemical properties. However, the plastic pallets will eventually result in visible and mechanical damages such as plastic aging, rupture, chipping, breakage, kinking due to the sun, temperature, humidity, beat, collision, scratching and other effects in the process of normal use. This damage is cumulative until its final failure, and so far it is hard to repair and restore. Therefore, the plastic pallets that differ from wooden pallets are typical non-repairable products.

It is clear that the deterioration model of the plastic pallet includes two factors-internal physical deterioration and external operational deterioration. The factors of so-called internal physical deterioration means the deterioration due to the aging process of plastic itself, resulting in cracking, deformation, deformation, the decreased ability of impact resistance and pressure resistance, while the external operational deterioration is referred to the damage caused by manual interaction during the process of handling, transportation, stacking, and forklift operation. This kind of damage is related to the working habits and regulations of operators.

Due to the inability to detect quantitative data on the aging of plastic materials, the existing method is to monitor the damage status of the pallet through appearance. In general, the years of physical and chemical aging of plastic materials is far longer than the service lifetime under normal environment and conditions of circulation, but the degree of aging will increase the probability of operational deterioration with the increasing using years.
Fig. 4 indicates the performance of plastic pallet deterioration without any maintaining intervention, concretely, variations of the plastic pallet deterioration at $t_1, t_2, t_3$ and $t_4$. In general, $X(t)$ is considered as a continuous monotone non-decreasing function of time. When the cumulative deterioration achieve a failure threshold $L$, plastic pallets will be eliminated.

To serve the purpose of the discussion, this paper constructs a cumulative impact model which combines factors of internal physical deterioration and the external operational deterioration. The quantitative parameters of the deterioration degree and available state of plastic pallet are mainly obtained through checking the surface of the plastic pallet. In the process of handling, operation and transportation, the structural damage due to the collision of forklift or throwing of goods can be observed and measured by the visual technology of machine, with respect to calculate the damaged area and the lateral area of the pallet which are called damage rates, thus we can determine the extent of damage. On the other hand, the lateral damage of plastic pallet cannot be repaired, and the damage rate will increase. After reaching a certain threshold, pallets would be eliminated.

The cumulative impact model assumes that the number of impact damage is a random variable, satisfying non-homogeneous Poisson process when plastic pallets are being used, in other words, the number of impact damage $N_{t+s}$ in the time interval $[t, t+s]$ is a non-homogeneous Poisson process involving intensity function $\lambda(t)$, that is to say

\[
P(N_{t+s} = n) = \frac{\lambda(t)\lambda(t+s)^{b} - \lambda(t)^{b}}{b^{n}n!} \cdot \exp\left(-\frac{1}{b}\left[\lambda(t+s)^{b} - \lambda(t)^{b}\right]\right), \quad n = 1, 2, \ldots,
\]

(4)

The significance of the intensity function is given in Fig. 5, although in the process of handling, the impact probability of plastic pallets can be considered to be stationary, almost the same with increasing time; but the damage probability of plastic logistics is increased with the aging of plastic material. We may conclude the number of impact damage at time $t_1$ is less than the number at later time $t_2$.

![Intensity function](image)

Figure 5. The significance of the intensity function.

Each impact will have a certain effect on the performance of the pallet logistics, which is related to the habit, equipment of handling and other factors. In such situation, for the purpose of
discussion, we can define that performance variation of each impact $Y_i$ is independent and identically normal distributed random variable

$$Y_i \sim N(\mu, \sigma^2) \quad i = 1, 2, ..., N_{t,t+s}$$  \hspace{1cm} (5)$$

where $\mu$ and $\sigma$ are performance parameters of plastic pallets, with $Y_i > 0$. Lateral failure rate is a measure of performance variation, with $Y_i \in (0, 1)$. Usually, $N_{t,t+s}$ and $Y_i$ are independent of each other.

Thus, we can define the number of performance deterioration in the time interval $[t, t+s]$ is the sum of performance deterioration of each impact during this time, that is

$$X_{t,t+s} = \sum_{i=1}^{N_{t,t+s}} Y_i$$  \hspace{1cm} (6)$$

Because $X_{t,t+s}$ is a compound Poisson process, $X_{t,t+s}$ can be regarded as a linear combination of normal distribution of $N_{t,t+s}$.

$$P(X_{t,t+s} < x) = \sum_{i=1}^{\infty} P(N_{t,t+s} = i)P\left(\sum_{j=1}^{i} Y_j < x\right)$$  \hspace{1cm} (7)$$

The formula above is more complex because $N_{t,t+s}$ and $Y_i$ are random variables.

According to the properties of the compound Poisson process, mathematical expectation and variance of performance deterioration in the time interval $[t, t+s]$ follow

$$E(X_{t,t+s}) = \frac{a\mu}{b} [(t+s)^b - t^b]$$

$$D(X_{t,t+s}) = \frac{a(\mu^2 + \sigma^2)}{b} [(t+s)^b - t^b]$$  \hspace{1cm} (8)$$

According to the central limit theorems, $X_{t,t+s}$ will be approximately normal distribution, that is to say

$$X_{t,t+s} \sim N(\mu_{t,t+s}, \sigma_{t,t+s}^2)$$  \hspace{1cm} (9)$$

where $\mu_{t,t+s}$ and $\sigma_{t,t+s}^2$ with

$$\begin{align*}
\mu_{t,t+s} &= E(X_{t,t+s}) \\
\sigma_{t,t+s}^2 &= D(X_{t,t+s})
\end{align*}$$  \hspace{1cm} (10)$$

Analysis of the reliability change – point
The possibility of failure increases greatly as cumulative deterioration of plastic pallet reach to a certain degree. The situation is similar to the bathtub curve $II$ in the Fig.3. The failure of the plastic
pallet is not determined by the failure of its own function, which is different from the equipment system. In the transfer process of elevated floor, flat floor or van, plastic pallet with a certain cumulative performance deterioration cannot meet the requirements of the job, even though it does not necessarily occur in itself, such as fracture, lack of angles and so on. In other words, the risk of the failure in transfer is greatly increased. In such situation, we call it reliability change–point. Hence, we may find that the failure threshold $L_s$ is determined by the job requirements in transfer.

Suppose that the failure rate in pallet transfer can be described as following

$$ r(l) = \begin{cases} 
  c_0 & l \leq L_s \\
  c_0 + c_1(l - L_s) & l > L_s 
\end{cases} $$

(11)

Where $l$ is a damage rate, also the ratio of the damaged lateral area and total lateral area, $L_s$ is the reliability change–point. Here we use the failure rate $l$ as the independent variable of failure rate instead of time $t$ for convenient estimation and the reliability change–point as the estimated value of the failure threshold for discussion and calculation. From Fig.2, we see that $c_0$ is the failure rate of accidental failure period, $a \geq 0$, $c_1$ determines the rising speed of the wear failure period.

Suppose that $l$ is the cumulative damage rate of plastic pallets, $N(l)$ is statistics of cumulative damage rate. For the purpose of statistics, the interval is divided into $N$ subintervals, that is

$$(l_i, N_i), i = 1, 2, ..., N$$

(12)

Then the model of cumulative failure rate can be expressed as

$$ N_i = \begin{cases} 
  c_0 + \varepsilon_i & 0 \leq l_i \leq L_s \\
  c_0 + c_1(l_i - L_s)^a + \varepsilon_i & L_s < l_i 
\end{cases} $$

(13)

where $c_0, c_1, a$ are parameters to be estimated, $\varepsilon_i$ is a observational error, satisfying $E\varepsilon_i = 0 (i = 1, 2, ..., N)$.

From the data of formula (12), we can use the least square method to estimate the parameters of the model. Firstly, we establish the objective function

$$ Q(c_0, c_1, a, L_s) = \sum_{i=1}^{N} \left[ N_i - \hat{N}_i \right]^2 $$

(14)

The approaching method of failure rate curve by fitting and grouped data by measuring is to minimize the objective function (14). Specific algorithm is:

Firstly, we estimate the accidental failure parameters $c_0$ in the time interval between point $I$ to $II$

$$ c_0 = \frac{\sum_{i=1}^{m} N_i}{m} $$

(15)
Then we use $N - m$ subintervals as a possible change-point in the interval $k \in [m, N)$, the objective function (14) can be written as

$$L(\hat{c}_0, \hat{c}_1, \hat{c}_2, k) = \sum_{i=m}^{k-1} N_i - \hat{c}_0 \right)^2 + \sum_{i=k}^{N} N_i - \hat{c}_0 - c_i(l_i - k)^2$$

(16)

For each possible change-point $k$, the estimated value $\hat{c}_1, \hat{c}_2$ of the parameter can be obtained. According to formula (16), we can calculate $L(k)$, and compare $L(m), L(m + 1), ..., L(N - 1)$. Among them, failure threshold $L_s$ is

$$L_s = \arg \left[ \min(L(m), L(m + 1), ..., L(N - 1)) \right]$$

(17)

**Evaluation of change-point**

![Image of different lateral damages of pallets](image)

Damage rate $l \approx 0.012$ damage rate $l \approx 0.083$

Figure 6. Different lateral damages of pallets.

The whole life cycle management system of pallets is unable to collect enough data to carry out large-scale pallet tracking, so this paper chooses 20 tested pallets with different damages to track and estimate the reliability change-point (different damage rates displayed in Fig.6). The probability of failure rate during the operational process of elevated warehouse and flat floor can be examined (The average value of the tracking number for each pallet is 32.6, shown in Table 1).
Table 1. Statistics on the failure rate of different pallets.

<table>
<thead>
<tr>
<th>Damaged pallet number</th>
<th>Cumulative failure rate</th>
<th>Tracking number</th>
<th>Failure rate</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.03</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.07</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0.12</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0.16</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.19</td>
<td>26</td>
<td>0.04</td>
</tr>
<tr>
<td>7</td>
<td>0.20</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.23</td>
<td>31</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0.26</td>
<td>32</td>
<td>0.03</td>
</tr>
<tr>
<td>10</td>
<td>0.28</td>
<td>35</td>
<td>0.03</td>
</tr>
<tr>
<td>11</td>
<td>0.29</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0.31</td>
<td>35</td>
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</tr>
<tr>
<td>13</td>
<td>0.35</td>
<td>33</td>
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</tr>
<tr>
<td>14</td>
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<tr>
<td>20</td>
<td>0.62</td>
<td>25</td>
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</tr>
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</table>

The interval of cumulative damage rates is divided into 50 subintervals, the statistical chart of the cumulative failure rate is shown in Fig.7.

Obviously, according to formula (15), we can get the parameter of accidental failure rate $c_0 \approx 0.003684 \ (m = 19)$, and calculate the curve $L(k)$ as shown in Fig.8.

Figure 7. Cumulative failure rate.
From Fig. 9, we observe that $k = 29$ and $L(29)$ is the minimum value, thus the estimates and value of corresponding failure rate of the failure threshold $L_s \approx 0.377$. That is to say, the cumulative damage rate (the ratio of the damaged area to the total area) is 0.377.

**Conclusion**

This paper has proposed a failure threshold of the pallet for the logistics service of company by devising the model based on data accumulated over the years of China Tobacco Zhejiang Industrial Co., Ltd. and theoretical basis. The results would provide a theoretical basis for the detection, scrap and establishment of the new purchase plan in company, and a scope of the future research on the transfer management of pallets after sharing would have a basis.

**References**


