A CONCEPTION OF THE MODERNISATION OF THE CHOSEN TRAMCARS’ MAINTENANCE SYSTEM

Key words
Tramcars, maintenance process, failure analysis, reliability, improvement of maintenance system.

Summary
A procedure of the modernisation of the maintenance system of the tramcars used in public transport was presented in this paper. The analysis is based on the maintenance information stored in the database of a city transport company. General and seasonal changes of the number of failures are analysed as well as their reasons and consequences. The effects of the failures are counted proportionally to the financial loss that is characteristic for each of tramcar. Using reliability indexes is essential for the proper description of the failure frequency of the tramcars were presented. The analysis allows one to evaluate the quality of the available information about maintenance process. Therefore, it may lead to decisions about improving the data storage system. The whole procedure provides information that is useful in choosing possible and effective ways of improving the maintenance system which will consequently lead to a reduction of the number of tramcars’ failures and a better
utilisation of financial resources. The results of the analysis are useful during
planning the times of maintenance work, the extents of regular servicing and the
supply of spare parts as well as the possibilities of modernising the rolling stock.

Introduction

To be able to undertake justified actions during the process of the
maintenance of tram carriages, it is necessary to have information regarding
their current technical condition and the occurring and predicted defects.

An analysis of the collected data can form a basis for planning, including
the inter-maintenance periods, the scope of the planned maintenance and
renovation works, a lists of the necessary spare parts and modernisation works
executed in order to minimise the failure frequency rate of the vehicles and to
improve the passenger transport and executed with the use of the available
technical equipment and financial resources.

In case of a transport corporation, it is possible through an introduction of
an efficient information system. The maintenance data and information shall
allow making justified decisions by all organisational units of the corporation,
which are responsible for the quality of the transportation process.

The presented analysis applies to tramcars functioning as a part of the
public and city transportation systems.

1. Characteristics of the process of maintenance of tramcars

Tramcars are used for providing transport services in the public and city
transportation systems. The vehicles are introduced into service as brand new,
used or modernised. Various organisational units of the transport corporation
participate in the process of maintenance of tramcars. This status requires an
efficient information flow as vital factors determining the correct execution of
the utilisation and maintenance of the analysed objects.

In this case, the reliability assessment is difficult, due to changing
conditions of the vehicle use. This pertains in particular to the following:
• Loads changing in time (intensity of the passenger currents),
• Parameters of the infrastructure with which the vehicle is working,
• Atmospheric conditions, and
• The people responsible for the execution of the maintenance process.

A large number of failures and financial outlays for repairing those defects
determine the necessity of introducing modernisation alterations in the public
transport fleet servicing system, its construction, and the system of obtaining
and managing the information regarding its maintenance.

In view of a large number of failures that have a negative effect on the
corporation finances, detailed guidelines shall be developed regarding the
schedule and the scope of the executed technical services which is preceded by a reliability study of the object and the actual situation at the servicing stations.

At the servicing station, the maintenance works are conducted either in accordance to the prescribed time intervals or after the specified mileage. The particular types of maintenance services are arranged hierarchically. Due to the economic aspect, it is important for the inter-maintenance periods pertaining to a wider scope of activities to be the multiplication of the inter-maintenance periods that pertain to the narrower scope of activities. Work organisation at the servicing station is directly connected to the fleet renewal schedule. Thus, it is necessary that the guidelines for servicing be reconciled to the requirements for maintaining the rolling stock with the technical and financial resources of the corporation.

The current maintenance system shall be modernised on the basis of conclusions drawn from the reliability assessment proposed in the study. Difficulties associated with the completed reliability study can form a basis for the assessment of the available maintenance information and may confirm the necessity of introducing changes in the information gathering, managing, and archiving system.

2. Failure analysis

Failures of the tramcars were classified in accordance to the following criteria: subassemblies to which the failure pertained, the number of failures, seasonal aspects, the reasons and effects of the rolling stock failures, and the costs of failure removal.

It allows the characterisation of particular types of failures with regard to their importance for the following processes: transport, vehicle utilisation, and supplying the service station or main workshops. Therefore, the characterisations are important to determine their importance for the functioning of the transport corporation.

Code abbreviations, which were used during all stages of the conducted analysis, were assigned to the particular types of failures.

Examples of the preliminary information processing used for the quantitative analysis of the failures are presented in Table 1.

The presented hypothetical data correspond to the actual tram maintenance process. They were assumed due to the proposed methodology of assessing the current status of the servicing system, while taking under consideration the modernisation potential.

The percentage of the particular types of defects in the total number of defects is presented using the Pareto-Lorenz graph which is presented in Figure 1.
Table 1. Example of the preliminary maintenance information processing

<table>
<thead>
<tr>
<th>No.</th>
<th>Subassembly</th>
<th>Code abbreviations</th>
<th>Number of failures</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Engine</td>
<td>105.1</td>
<td>41</td>
<td>3.2%</td>
</tr>
<tr>
<td>2.</td>
<td>Rheostatic starter</td>
<td>105.2</td>
<td>38</td>
<td>3.0%</td>
</tr>
<tr>
<td>3.</td>
<td>Current collector</td>
<td>105.3</td>
<td>6</td>
<td>0.5%</td>
</tr>
<tr>
<td>4.</td>
<td>Gear unit</td>
<td>105.4</td>
<td>7</td>
<td>0.6%</td>
</tr>
<tr>
<td>5.</td>
<td>Mechanical brake</td>
<td>105.5</td>
<td>141</td>
<td>11.1%</td>
</tr>
<tr>
<td>6.</td>
<td>Rail brake</td>
<td>105.6</td>
<td>122</td>
<td>9.6%</td>
</tr>
<tr>
<td>7.</td>
<td>Doors</td>
<td>105.7</td>
<td>416</td>
<td>32.8%</td>
</tr>
<tr>
<td>8.</td>
<td>Lighting</td>
<td>105.8</td>
<td>196</td>
<td>15.4%</td>
</tr>
<tr>
<td>9.</td>
<td>Ring</td>
<td>105.9</td>
<td>26</td>
<td>2.0%</td>
</tr>
<tr>
<td>10.</td>
<td>Others</td>
<td>105.10</td>
<td>277</td>
<td>21.8%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td>1272</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

From Figure 1, it is possible to determine that 80% of failures pertain to 4 types of vehicle failure, which comprise the “weak links” of the analysed objects.

![Fig. 1. Pareto-Lorenz graph for data presented in Table 1](image)

Analysis of the seasonal aspect of failures and the general trend of changes in the number of defects over time for the particular types of failures are presented using bar graphs.

An exemplary histogram is presented in Figure 2. It shows the changes in the number of failures during the consecutive 24 months.

The curve (the trend line) shows a significant rise in the number of failures caused by a natural wear and tear process and the process of ageing, which are intensified due to the atmospheric conditions, particularly during autumn and winter months.
The influence of the number and types of failures on the corporation’s financial condition led to the necessity of also taking into consideration in the analysis the economic factors that formed a basis for the conducted evaluations.

The proposed coefficients allow one to estimate the global costs incurred by the corporation. Those indicators include the following:

- The failure effect coefficient, and
- The failure importance coefficient.

The significance of the particular types of failures can be established by determining the total value of losses associated with those failures and their influence on the selected zones in which the corporation is operating. This value was determined as a failure effect coefficient, and it was denoted with the $W_{SUij}$ symbol. It pertains to the failure of the $i$ type (selected from the set of $1...n$ of the analysed types of failure), occurring in vehicles of the $j$ type. The method of calculating this value is presented with the use of Formula (1) [4].

$$W_{SUij} = 100 \frac{S_{Uij}}{\sum_{i=1}^{n} S_{Uij}}$$ (1)

In this notation, symbol $S_{Uij}$ denotes the total value (the sum) of losses incurred by the corporation as a result of a single incident of the $i$ type failure, occurring in the $j$ type vehicle. The sum in the denominator represents the total value of losses, which are associated with a single incident of failures of the all – $n$ – analysed failure types. The purpose of the “100” coefficient, which was included in the formula, is to increase the scope of the variation of the coefficient, which makes it easier to compare different values of this coefficient that are determined during the analyses.

The value of the sum of all losses $S_{Uij}$ includes losses in all analysed areas, when those losses pertain to the processes specified above, for example, the sum of all losses can be determined using Formula (2).

$$S_{Uij} = \frac{W_P \cdot K_{plj} + W_E \cdot K_{Eij} + W_Z \cdot K_{Zij}}{W_P + W_E + W_Z}$$ (2)
where:

- \( K_{Pi}, K_{Ei}, K_{Zi} \) - losses associated with the \( i \) type failure, occurring in the \( j \) type vehicle, related to (accordingly) the disruption of the transport process, the completion of repair work at the service station, due to the failure, and the necessity to supply the corporation’s organisational units with resources required to repair the damage.

- \( W_{Pi}, W_{Ei}, W_{Zi} \) - coefficients, allowing to compare the costs of various types of losses, are associated with the effects of the various character of failures.

The \( S_{Uij} \) value can also represent losses in sectors other than the ones analysed so far. Its estimation is determined by the availability of the necessary data, characterising the losses associated with the occurring failures.

The analyses conducted with the use of the presented failure effect coefficient applies only to losses associated with a single occurrence of the particular type of failures; however, in real life, the functioning of the corporation is most affected by the actual number of such occurrences. This factor was characterised by the frequency \( c_{ij} \), defining the number of incidents involving the \( i \) type failure in the \( j \) type vehicle, during the period of the conducted analyses. This value is determined using Formula (3).

\[
c_{ij} = \frac{l_{ij}}{\sum_{i=1}^{n} l_{ij}}
\]

(3)

where:

- \( l_{ij} \) - number of incidents involving the \( i \) type failure in the \( j \) type vehicle, during the entire period of the analyses;
- \( \sum l_{ij} \) - total number of failures of all \( n \) types (\( i = 1...n \)) in the \( j \) type vehicle, during the entire period of the analyses.

The amount of losses associated with the \( i \) type failure in the \( j \) type vehicle, when taking into consideration both the single incident and the total number of incidents was described by the failure importance coefficient - \( W_{ZUij} \), which is described by Formula (4), in which the earlier described failure effect coefficient (1) and the frequency coefficients (3) were used [4].

\[
W_{ZUij} = W_{SUij} \cdot c_{ij}
\]

(4)

The obtained values can be presented using various commodity units (PLN, service station employee working hours, without any units, etc.), depending on
the method of the representation of the appropriate costs assumed for the
determination of the value of incurred losses (2) and coefficients, which were
introduced to allow for the comparison of those costs.

The more precisely the types of the analysed failures are specified and the
more precisely the losses associated with each of those types of failures are
described, the more accurately can the importance of the failure effects in the
assumed calculation model be determined.

Other factors associated with the occurring failures, such as circumstances
in which the failure occurred, or the influence the specific failure had on another
failure, can also be important. This can form a basis for the further development
of the presented model. However, in each case, it is dependent on the quality
and the type of the available maintenance data.

As a result of the conducted calculations, the highest values of the failure
importance coefficient will be assigned to those failures, which have the
uppermost importance for the functioning of the transport corporation.

It can happen that the failure, which is characterised by a very high value of
the failure effects coefficient, will not assume the highest value of the failure
importance coefficient due to a low frequency of such incidents. This is
reflected by a situation where failures, which require relatively high outlays
associated with their repair, but which occur relatively rarely, are a much
smaller burden for the corporation than a large number of failures repaired
faster and at lower costs.

The possible causes of the occurring failures shall also be analysed, while
taking into consideration the operational conditions of the analysed objects.

3. Reliability assessment

The reliability assessment shall, in particular, pertain to those components
and elements that have the greatest influence on the functioning and financial
losses of the corporation. The reliability assessment requires information
resources, which allow one to precisely determine the moments when the
particular types of failures occurred.

In the assumed assessment model [3], the relation of the work time of the
particular objects, until the moment the failure occurred, was analysed. This
allowed us to determine the reliability characteristics.

From the most frequently used distribution models used in the reliability
assessment, the Weibull distribution model was selected. This was justified by
its being best matched to the data, which was proven using the Kolmogorov test.
The Weibull distribution model allows one to analyse the reliability of technical
objects at all stages of their life cycle.
The distribution parameters were determined on the basis of the methodology described in [3] and with the use of the highest credibility method [1]. Calculation results for work times for the first failure are presented in Table 2.

### Table 2. Parameters of the Weibull distribution

<table>
<thead>
<tr>
<th>Method</th>
<th>Calculation due to the model [3]</th>
<th>Calculation due to the highest credibility method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter Shape δ</td>
<td>1.1567</td>
<td>1.1614</td>
</tr>
<tr>
<td>Scale θ</td>
<td>8.0175</td>
<td>8.2511</td>
</tr>
</tbody>
</table>

The analysis of the coherence of the theoretical distribution with the empirical one led to obtaining the p-value, which equals around 0.95.

For these calculated values of the Weibull distribution parameters, the reliability characteristics were obtained as follows:

\[
R(t) = e^{-\frac{t^{1.2}}{8.0}}; \quad F(t) = 1 - e^{-\frac{t^{1.2}}{8.0}}; \quad f(t) = \frac{1.2}{8.0}t^{1.2-1}e^{-\frac{t^{1.2}}{8.0}}; \quad \lambda(t) = \frac{1.2}{8.0}t^{1.2-1}
\]

There are expressed by dependencies presented in Figure 3.

![Figure 3](image_url)

**Fig. 3.** The characteristics: reliability function, cumulative frequency, probability density function and failure rate for the distribution parameters: \( \delta = 1.1614 \) i \( \Theta = 6.1538 \)

An indication of the stage of life cycle of the analysed technical object can also be done with the use of the failure stream parameter \( \Lambda \) [2]. The empirical value of the parameter is determined in accordance to Formula (5) as follows:

\[
\hat{\Lambda} = \frac{n_{\Delta t}}{n_0 \cdot \Delta t}
\]

(5)

where:

- \( n_{\Delta t} \) – number of defective objects, during the analysed period of time \( \Delta t \);
- \( n_0 \) – total number of examined objects;
- \( \Delta t \) – period of time used for the analysis.
In the exemplary calculations, the following values were assumed:
\( n_0 = 100 \) – total number of examined objects;
\( \Delta t = 1 \) month – period of time used for the analysis.

The obtained values are presented in the form of a graph (Fig. 4).

![Graph](image)

Fig. 4. The values of the failure stream parameter of tramcars’ doors

The trend line presented in Figure 4 shows that the number of failures increases in time, which is associated with the ageing of the analysed objects.

4. Results of the conducted analyses

Activities undertaken in order to conduct the modernisation of the tramcars’ maintenance system are presented in Figure 5.

![Diagram](image)

Fig. 5. The procedure of the modernisation of the maintenance system
The run of the reliability characteristics allows the determination of the probability of failure in the selected time units. When assuming the typical number of kilometres driven during a specific unit of time (e.g. one day or one month), it is possible to determine the failure probability values for the mileage at which the technical and maintenance services were conducted. The comparison of the obtained results with the assumed values can form a basis for the modernisation of the schedule and the scope of the conducted technical and maintenance services.

In case of the failure of components and elements, the repair of which require greater financial outlays, a detailed analysis of the failure causes is required in order to develop new guidelines and procedures for the servicing stations. Detailed maintenance information plays a great role here. The collected information can also be used as a basis for the technical modernisation of the vehicles.

The information system used by the transport corporation needs to be modernised, allowing the creation of databases that will permit conducting detailed identification of failures, particularly the most expensive repairs.

The obtained information regarding the reliability of tramcars can be useful for the process of spare parts purchase planning for those organisational units of the corporation that are involved in the process of servicing tramcars. The reliability characteristics forms a basis for determining the necessary supply of spare parts, while at the same time, it helps in reducing the warehousing costs of spare parts.

The run of the failure rate function and the trend line, which are denoted on the bar graph of the empirically determined values of the failure stream parameter, indicate the stage of the life cycle of the analysed vehicles. The analysis of the run of the failure stream parameter, together with the information regarding the conditions in which the vehicles were used, can form a basis for the modernisation of the vehicles’ structure and changes in the servicing system while taking into consideration the actual costs.

Summary

The selection of activities undertaken in order to limit the failure frequency rate of the used technical objects is supported by a detailed analysis. The analysis of the consequences of the occurring failures and the reliability analysis indicate the courses of the most effective actions. The experience of persons directly engaged in the process of the utilisation and servicing of the analysed objects can also prove to be a valuable source of guidelines.

The results of the conducted analyses depend on the quality of the available maintenance data. This data can facilitate the management of the tramcar maintenance with the best utilisation of the available resources.
References


Koncepcja modernizacji systemu obsługiwania wybranych wagonów tramwajowych

Słowa kluczowe
Wagony tramwajowe, proces eksploatacji, analiza uszkodzeń, niezawodność, poprawa systemu obsługiwania.

Streszczenie

W opracowaniu przedstawiono procedurę modernizacji systemu obsługiwania wagonów tramwajowych funkcjonujących w komunikacji miejskiej. Działa nia podejmowane są w oparciu o informację eksploatacyjną zgromadzoną w bazie danych przedsiębiorstwa transportowego. Przeprowadzona analiza oraz zaproponowana metodyka ocenowa uwzględniają koszty ponoszone przez przedsiębiorstwo. Przedstawione charakterystyki niezawodnościowe stanowią podstawę działań modernizacyjnych w zakresie systemu obsługiwania.

Zaproponowana procedura pozwala na ocenę procesu obsługiwania oraz realizację zmian mających na celu poprawę niezawodności. Zmiany powinny również dotyczyć funkcjonującego w przedsiębiorstwie systemu informacyjnego.