Transport Vehicle Maintenance Optimization

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Abstract. The successful maintenance of transport vehicles in operable condition is facilitated by the proper assessment of their technical condition and forecasting its changes. The efficient operation of vehicles is only achieved if the changes in the engine load in the forecast cause changes in the dynamics of technical condition parameters. Besides, forecasting can help reduce vehicle repair costs. The forecasts are based on vehicle component, assembly, and subsystem failure statistics over a certain period. We must understand that the overall failure values include both gradual and sudden ones. While classifying failures as gradual or sudden when performing repairs is not challenging, forecasting sudden failures is quite difficult. We suggest failure forecasting methods based on the statistical sampling and in line with the following assumptions: Gradual failures are associated with the intensive operation of vehicles and their changes are proportional to the changes in vehicle operation duration. Sudden failures do not depend on the vehicle workload but have an inverse effect on it: the more sudden failures there are, the less useful work vehicles can perform. Thus, it is possible to describe the changes in gradual and sudden failures over time. It can expand the theoretical understanding of vehicle operation and provide repair forecasting tools to operators and maintenance companies.

1. Introduction
The efficient operation of transport vehicles requires certain technical maintenance (TM) and repair works [1–6]. As a rule, these works are mentioned in the reference documentation and user manuals [7]. Apart from the scheduled repairs, other faults and failures are identified and eliminated during the TM. Gradual failures associated with the deterioration of vehicles’ technical condition due to their intended use can be forecast using relatively simple methods and prevented by certain repair and maintenance procedures [8]. Sudden failures happen accidentally and they cannot be predicted using any patterns. Such failures lead to vehicle and machinery downtime, as well as repair costs. Sudden failures can be caused by design features, low quality of materials, or operational conditions of vehicles [9]. We believe that in the context of wide usage of information technologies to register in detail vehicles’ operating time, fuel consumption, repair and maintenance works, as well as a spare part and material consumption, it is possible to improve sudden failure forecasting using big data to identify the patterns of their occurrence [10–12].

2. Theoretical basis
The operating time of transport vehicles in active use varies around an average value, which can also change over time. Let us assume that the (daily, weekly, or monthly) operating time varies according to the following function (Figure 1):

\[ W = f(t) \]
The failures rate over the same periods will vary according to the following function:

\[ N = g(t) \]  

(2)

Gradual failures take up about 70% of the failure aggregate. Since their number depends on the operating time and is proportional to it, we can claim that function (3) describing the changes in gradual failures will be the same as the operating time function, and the graphs of the two functions will be parallel (Figure 2).

The gradual failure function will look as follows:

\[ N_g = h(t) = A f(t+B) \]  

(3)

where \( A \) and \( B \) are correction factors.

Figure 1. Changes in transport vehicle operating time and failures over time.

Figure 2. Changes in gradual failure number over time.

Sudden failures cannot be forecast but their (net) impact on the operating time of vehicles is quite clear: the more sudden failures there are, the less the operating time is, and vice versa (Figure 3):
The visualization of the sudden failure curve will be symmetrical with the operating time curve (about a hypothetical axis that does not have to be parallel to the X-axis). The sudden failure function will look as follows:

\[ N_s = k(t) = C - D f(t+E) \]  

where \( C, D, \) and \( E \) are correction factors.

Based on the above, function (2) in expanded form with regard to (3) and (4) will look as follows:

\[ N = g(t) = A f(t+B) + C - D f(t+E) + r(t) \]

where \( r(t) \) is a correction function.

Therefore, we can suggest the following algorithm for gradual failure forecasting and alleged sudden failure pattern identification:

1) based on the analysis of the transport vehicle operating time statistics, the operating time dependence can be approximated;
2) based on the analysis of the transport vehicle failure statistics, the time and failure dependence can be approximated;
3) using expression (3), we can suggest a dependency to describe changes in the number of gradual failures;
4) using expression (5), we can determine a possible dependency pattern for sudden failures;
5) with \( r(t) \neq 0 \), we shall change the values of \( A, B, C, \) and \( D \) incrementally until the correction function equals to zero.

3. Experimentation

We monitored a bus fleet at a motor carrier. The fleet comprised 33 buses. We analyzed the data collected between January 1st and December 31st, 2018. We recorded distances traveled daily, as well as fuel and spare part consumption. As of the failures were classified according to the subsystems of the buses. Within the year, a total of 3310 failures took place that required spare part replacements including 1064 engine failures, 993 chassis failures, 581 electrical equipment failures, 276 driver’s cab, and passenger compartment problems, 205 transmission faults, and 191 pneumatic system failures. In the analysis, we excluded the statistics for January because scheduled repairs were performed during this month which we did not include in the failure statistics.

The distance traveled statistics can be represented as a histogram or a graph (Figure 4):
The points on the experimental curve can be approximated using the following dependency:

$$L = 0.1876t^3 - 4.6948t^2 + 31.635t + 262.4545$$

(6)

with the correlation index of 0.898 and the mean error of 1.391%.

**Figure 4.** Distance traveled by buses in thousands of km.

**Figure 5.** Distance traveled by buses, experimental points, and the theoretical curve.

The engine failure graph according to the statistics looks as follows:
The points on the experimental curve can be approximated using the following dependency:

\[ N = 0.327t^3 - 8.926t^2 + 70.887t - 67.152 \]  
with the correlation index of 0.664 and the mean error of 22.86%.

Let us concede the gradual failure dependency from dependency (6):

\[ Ng = 0.1876t^3 - 4.6948t^2 + 31.635t + A \]  
To determine the sudden failure dependency, let us subtract dependency (7) from dependency (8):
\[ N = 0.327t^3 - 8.926t^2 + 70.887t - 67.152 \]
\[ Ng = 0.1876t^3 - 4.6948t^2 + 31.635t + A \]
\[ Ns = 0.1394 t^3 - 4.231 t^2 + 39.252 t - A - 67.152 \]

Variable \( A \) cannot be determined when passing from expression (6) to (8). We can determine the variation limits for the free polynomial term based on the condition that \( Ng \) and \( Ns \) cannot have negative values.

The calculations show the minimum value for \( A \geq 32 \); i.e.
\[ Ns = 0.1394 t^3 - 4.231 t^2 + 39.252 t - 99.152 \] (9)

In this case, the sudden failure dependency looks as follows:
\[ Ng = 0.1876t^3 - 4.6948t^2 + 31.635t + 32 \] (10)

4. Conclusions
The application of our methods can help obtain analytical dependencies for gradual and sudden failures in transport vehicles [13, 14]. The theoretical concepts associated with the changes in the number of failures can be verified by experiment during the next scheduled transport vehicle operation period. The probability of failure forecasts can also be determined. This is especially important for sudden failures that have been impossible to predict until recent times.

5. References
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