Computerization of rail vehicles maintenance systems
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Abstract

In the paper the problems of rail vehicle maintenance are solved in three levels; the theory of systems is utilised for the analysis of a transport means with the output on the maintenance quality, the mathematical model of maintenance process optimisation which can be practically utilised by use of computer, and an example of real existing vehicles maintenance system modelled by use of commercially available software. The possibilities of computer processing of statistical data of transport means reliability and failures are analysed. Possibilities of maintenance works combinations and variations are studied by use of software for project management.

1 Introduction

The modern repair and renewal methods of transport means tend to perform maintenance tasks depending on the real technical state of a vehicle which has the aim of minimising the maintenance costs, but as well has an effect on optimisation of vehicle’s structural parts and aggregates. These tasks have to be solved in a system approach.

At present there are trends toward new forms of organisation and techniques of total repair process of rail vehicles aiming at rationalisation and economic effectiveness. This important tasks require a system solution, considering technological, technical and human resources.
Computers in Railways

Owing to long experience in transport operation, theoretical, research, experimental and practical activities in the field of maintenance and repairs of transport means, the Department of machinery maintenance engineering of the Faculty of mechanical engineering of the University of Zilina (e.g. Herzan et al [1]) was asked by the Ostrava municipal transport company (Czech republic), to assist in rationalisation project of repairs of trams in the Martinov repair works.

2 System approach to transport means

Transport means as a complex system with required properties can be studied in several levels. These levels determine its planned and in operation expected parameters. The parameters have to be set for design and operational exploitation in following main areas:

- design and structure of transport means of advanced concept
- new operational properties with high safety standards
- modern methods of maintenance and reconstruction
- optimisation of operational and maintenance costs

It is generally known that the above mentioned characteristics will be satisfied when a transport means is approached as a system with required properties. Then, for determination of this system, the elementary tasks can be characterised as:

1. creation of means that enable description of objects examined as systems,
2. creation of systems' models and specific properties, including a model of system dynamics, their purpose behaviour, hierarchical composition, control processes, etc.

In the process of investigation and determination of the system parameters of transport means, first of all, the principles of international quality standards have to followed. In general, creation and realisation of the quality system is required to keep certain structure and should contain:

- definition of quality - assessing the importance of quality for the manufacturer
- role of the quality in competition,
- determination of relations with external and internal customers,
- emphasis on positive motivation of human factor,
- preference of quality improvement and not only its management,
- assessment of roles of all producing workshops in securing quality.
The basic assumption for creation of a new approach to the design, operation and maintenance of transport means is the analysis of requirements asked from transport means parameters and creation of method of parameters choice. The method should consider the parameters as a system. These are focused on operational quality, environmental protection and also optimisation of maintenance and reconstruction of transport means, especially according to real technical state of a vehicle.

Let us define the parameters required from railway vehicle with the aim of creation of system viewpoint in the first approach, then we consider especially following properties: safety, power, speed, reliability, failures, maintainability - reconstruction, energy consumption, function of quality and structure, vehicle control, ecological parameters = effects on the environment, riding comfort, artistic design, etc.

From the above presented one can see that the individual properties represent unique subsystems, which are again very complex, that means the problem solution for the individual systems has to have its own theory, terminology, object of research and realisation application, as well as its experimental methods. This emphasises how complex and time demanding these tasks are and how they call for a team work.

Possible functional scheme for the development of new transport means and evaluation of already operational ones is presented in the figure 1.

![Functional scheme of reliability analysis for needs of maintenance.](image-url)
3 Determination of maintenance parameters

When proposing a maintenance system of a rail vehicle, the economic aspects have to be considered, too. Although the preventive maintenance is prevailing, a maintenance according to real technical state of a vehicle should be gradually introduced into operation. Based on these assumptions, it is possible to create a new maintenance strategy with consideration of:

- reduction of the number of maintenance works when checking a real technical state of the element which can be characterised by suitable physical parameter,
- calculated periodicity of maintenance works based on estimated technical life of each element,
- operational conditions of railway vehicle with definition of degree and range of maintenance,
- possibilities of extending life of each element which is exposed to wear or another change of parameter.

It is evident that to fulfil these requirements, the methods of mathematical statistics, theory of maintenance and diagnostics have to be applied, together with efficient use of PC and information systems.

In repair workshops the question is how to govern the repair process which is stochastic in its substance. From this reason it is more demanding on sources, planning, organisation and control of the process.

In modern approach in railway repairing industry, the following problem areas are being solved:

- project management (of repair process),
- arrangement of repair lines,
- repair process simulation.

At present it is effective to solve the above presented areas by use of computer technology as part of CIM in application to repairing conditions. In CIM system it is possible to separate the following subsystems:

1. strategic planning of enterprise
2. marketing
3. development and design (CAD)
4. technological prepare of production (CAPP)
5. production planning systems (PPS)
6. operative production management and automated manufacturing (CAM)
7. projecting of production means
8. quality and service (CAQ)
3.1 Statistic and parametric reliability

Methods of statistic and parametric reliability are basis for creation of a proposed maintenance system. This requires a knowledge of system’s elements reliability. From the system point of view, a vehicle is a system of elements, or subsystems. A system can be expressed in terms of scheme in which the function links of elements are shown.

The elements’ reliability can be expressed in terms of basic statistic characteristics. Expression of characteristics depends on probability distribution (behaviour of element). Very convenient is use of the Weibull probability distribution:

Knowledge of the time change of the parameters (including their stochastic character) is inevitable for creation of the failure model.

For the analysis of technical state and prognosis of reliability of the transport means it is important to create and investigate the failure model. The initial values of parameters depends on structural parts designs, technology of their manufacture and operational conditions. The real limit state of the part is the state of the part when the failure occurs. The limit state (e.g. dimensions, shape, physical properties, etc.) are given in technical specifications by manufacturer or can be obtained experimentally or in operation. If they have a normal probability distribution then the probability that the parameter does not exceed the limit value is given by eqn (1) (Stuchly [3]),

\[
R(T) = 0.5 + \Phi \left( \frac{Y_{\text{max}} - a_{\text{mean}} - v_{\text{mean}} \cdot T}{\sqrt{\sigma_a^2 + \sigma_v^2 \cdot T^2}} \right)
\]

where \( R(T) \) - probability the parameter does not exceed the limit (-)
\( \Phi \) - Laplace function
\( Y_{\text{max}} \) - limit value of parameter (e.g. mm)
\( a_{\text{mean}} \) - mean initial value of parameter (e.g. mm)
\( v_{\text{mean}} \) - mean speed of parameter's change (e.g. mm/hour)
\( T \) - time to failure (e.g. hour)
\( \sigma_a \) - standard deviation of initial value of parameter \( a \) (-)
\( \sigma_v \) - standard deviation of speed \( v \) (-)

This model is shown in figure 2. Other models can be found in references (Stuchly [3]).
3.2 Optimisation of maintenance cycle

For the determination of the optimum maintenance period (mileage between repairs) it is necessary to have knowledge on analytical dependencies of costs for keeping operational state and repair of the investigated element on given (suggested) mileage between repairs.

Relation for estimation of relative costs of repair can be obtained by using eqn (2):

\[
U = \frac{\int_{0}^{\infty} R(l).dl}{\int_{0}^{\infty} R(l).dl} \cdot [1 - (1 - m).R(L)]
\]  

where:  
- \( U \) - relative cost of repair (-)  
- \( R(l) \) - probability density of run without failure (-)  
- \( m \) - ratio of costs for planned and not planned repairs (-)  

In figure 3, the curves of relative costs of repair \( U \) for various ratios of costs \( m \) for Weibull distribution with parameter \( b = 6 \) are presented. One can see that minimum depends on ratio \( m \). The optimal maintenance period is calculated then by using eqn (3),

\[
l_{opt} = l_U \min \cdot a
\]
Relative Costs $U$

(Weibull distribution, $b = 6.0$)

Figure 3: Function of $U$ for Weibull probability distribution (shape parameter $b=6$)

The optimal maintenance system (cycle) for a vehicle then can be calculated from optimal maintenance periods $l_{opt}$ of individual elements using object function given by eqn (4),

$$q(l_1,a_2,a_3,\ldots,a_n) = \sum_{i=1}^{n} \frac{C_i}{L_i} = \sum_{i=1}^{n} \frac{C_i}{(a_i \cdot a_{i-1} \ldots a_2) \cdot L_1}$$

(4)

where:
- $q$ - cost of repair per kilometre (Sk/km)
- $C_i$ - maintenance (repair) costs of $i$-th element, (Sk)
- $a_i$ - ratio of runs (mileages) between two repairs (must be integer)
- $L_i$ - mileage between maintenance of $i$-th element, (km)

Further a simple example of determination of optimal maintenance cycle is shown. The system composed of four structural parts where for each structural part an optimal maintenance period was estimated using equations (2) and (3). (see 2nd column in the Table 1). Then using the equation (4) the optimal maintenance terms (mileage) for the system and maintenance categories resulted (see 4th and 5th columns of Table 1).
Figure 4: Values of relative costs $q$. Optimal mileage 77 km.

Table 1

<table>
<thead>
<tr>
<th>Structural part</th>
<th>Optimum maint. period of i-th part (mileage)</th>
<th>Maintenance costs of i-th part</th>
<th>Maintenance term (mileage)</th>
<th>Maintenance category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96</td>
<td>35</td>
<td>77</td>
<td>A</td>
</tr>
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</tr>
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<td>183</td>
<td>195</td>
<td>154</td>
<td>B</td>
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<td>4</td>
<td>308</td>
<td>500</td>
<td>308</td>
<td>C</td>
</tr>
</tbody>
</table>

Figure 5: Determination of optimal maintenance cycle for system with 4 elements.
4 Project management in repair process

One important part of maintenance process is the analysis of reliability and processes of elements deterioration and failures. The above presented methodology can be used for suggesting the optimal mileage periods and maintenance systems. The other step in maintenance process rationalisation is to optimise maintenance procedure itself. First stage of this is to analyse repair procedure and organisation and identify critical tasks (or bottle-neck operations) in this procedure. As mentioned before, our department was asked by the Ostrava municipal transport company, division of trams, to assist with the project of trams repair process rationalisation.

For this purpose methods of project management have been used. Generally, project management consists of three phases:

Creation of the project - this is a very important phase, as its comprises tasks definition and their duration, it determines relations among tasks and allocates resources to individual tasks. All other phases of project management are depended on information given in the phase of project creation.

Management of the project - this is a continuous phase which starts with project creation and finishes when the project is completed. Project management consists of monitoring and verifying the project and reacting to changes which occurred during the project.

Creation of reports on the project - in this phase the information obtained is presented. It is very important to have a possibility of quick and simple creating of information reports.

In the project of trams repair process rationalisation the first step was to acquire the data on the current repair process. The most used type of tram, CKD TATRA series T3, was chosen. The data describing a repair process were obtained by consultations and cooperation with staff from Martinov repair workshop. After loading data into computer they were processed by Microsoft project software package. The main output were Gantt charts of repair procedures where the critical path was clearly visualized. Other outputs were PERT diagrams, resource allocation and resource usage graphs, etc. In figures 6 and 7 examples are presented.

The main advantage of computerized project management was that we were able quickly do many alternative studies by means of rescheduling the tasks and resource allocations. The analysis showed, that the most critical tasks were painting operations. By some "rationalization reshuffling" the total repair time could be reduced by about 20%.
Figure 6: Gantt chart of tram series T3 medium repair.

Figure 7: PERT diagram of tram series T3 medium repair.

References