

# Change in the maintenance strategy as a method of improving the efficiency of the process of operation of railway means of transport

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**Abstract.** The paper presents a description of methods of changing the maintenance strategy concerning measures of intervals between maintenance levels based on the example of a selected railway vehicle type. The process starts with monitoring the vehicle after it is put into operation and the operational database is built, through the statistical and RAMS analyses, to the approval of changes in the maintenance system documentation by qualified railway safety bodies. Following the applicable formal and legal requirements, one of the key problems involved in the introduction of changes in the railway vehicle maintenance system is an assessment of the proposed changes for safety.

## 1 Introduction

Projects intended to improve the efficiency of the process of operation (use and maintenance) of means of transport are amongst the fundamental areas of the strategies pursued by rail transport companies. In the group of maintenance projects, particularly noteworthy is the change in the maintenance strategy concerning the maintenance plan structure and the change in the measures of intervals between checks and scheduled repairs (so-called maintenance levels). Reduction of preventive maintenance costs and implementation of modern maintenance methods, such as Condition-Based Maintenance (CBM) is the subject of many scientific publications devoted to this issue [1-3]. The research and development work, which were done on the change in the maintenance strategy [4-10], prove that the costs of preventive maintenance of railway means of transport form up to 30,5% of the Life Cycle Costs (LCC) and are the second dominating cost category after the costs of power or fuel consumption. Currently, such projects are very often applied by Polish railway carriers. Following the model of leading foreign companies, in their strategic ventures, Polish carriers intend to introduce dynamic maintenance plans in which the criterion for referring a vehicle to a check /repair are measurements the vehicle actual operational work.

On the basis of an analysis of the writings and the experience gathered in conducting research and development work for Polish railway carriers, e.g.: [11-13], Table 1 presents a description of the praxeological sequence illustrating the change in the maintenance strategy concerning the measurements of intervals between checks and scheduled repairs with the fulfilment of the following criteria:

- ensuring a high level of safety in railway transport,
- ensuring effective outlays on maintenance.

The process starts with monitoring the vehicle after it is put into operation (purchased or modernised) and the development of an operational database, through a statistical and reliability analysis of the data, risk analysis of the proposed changes, to the approval of the changes in the maintenance system by the authorised railway safety bodies [14].

## 2 Example of method application

The method for changing the maintenance strategy is universal in its nature and may be applied to various types of rail vehicles (diesel and electric traction vehicles, cargo and passenger carriages). This paper presents selected aspects based on the example of a modernised diesel 6Dg type locomotive (Fig. 1).



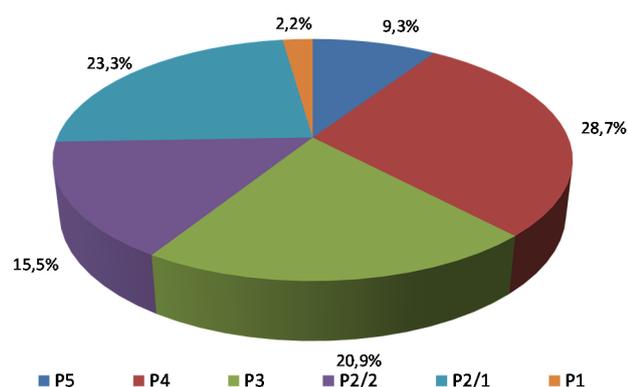
**Fig. 1.** View of the 6Dg diesel locomotive (photo: M.Górowski).

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**Table 1.** Description of the method of change of the maintenance strategy concerning the measurements of intervals between checks and scheduled repairs [14].

| No. | Name  | Description of stage   |
|-----|---|--|
| 1   | Development of operational database                                       | Operation monitored from the start of operation until the first repair at the P4 level. Collection of operational data concerning: kilometrages and time of operation (km/year, hr/year), time to failure, times of modernisation, causes for failures, costs of repairs. Archiving preventive maintenance documentation.  |
| 2   | Formal requirements for the maintenance system                            | Analysis of the applicable law concerning the maintenance system and changes in rail vehicle maintenance systems.  |
| 3   | Statistical analysis of the operational process                           | Analysis of statistical data on kilometrages and time of operation between maintenance levels and comparison with the assumptions in the maintenance system documentation.   |
| 4   | Concept of changes in the maintenance process                             | Collection of practical knowledge from specialists from the Rolling Stock Maintenance Department about the possibility to change the maintenance plan for the analysed vehicle. Proposal of changes in the maintenance plan, comprising a change in the measurements of intervals between the maintenance levels and the scopes of activities within the Maintenance System Documentation (DSU).   |
| 5   | RAMS analysis in the area of safety                                       | Structure of failures. Identification of locomotive assemblies, subassemblies and elements (so-called relevant elements). Analysis of reliability data. Identification of models of distribution of probability of time of operation to failure and time of modernisation for vehicle assemblies and subassemblies. Identification of durability and reliability characteristics and RAMS indices. |
| 6   | Risk analysis for the proposed changes                                    | Analysis of the risk involved in the proposed changes in accordance with Regulation (EU) No 402/2013 comprising: assessment of the relevance of changes, defining the system, identification of the interfaces, identification of hazards and risk assessment.   |
| 7   | Assessment of the effectiveness of the changes in the maintenance process | Comparison of the costs of preventive maintenance before and after maintenance plan changes.   |
| 8   | Approval of changes in the maintenance system documentation               | Minor changes (according to Regulation 402/2013) are approved by the railway company management board whilst significant changes require the approval by the accredited body which supervises and verifies the correctness of the risk assessment process.   |

The analysis was the subject of a series of research and development papers [15-17]. Identification of the LCC cost structure of the 6Dg diesel locomotive demonstrated that scheduled checks done at the P2 level (P2/1 and P2/2 totalling 38,8%) and scheduled repairs done at the P4 maintenance level – 28,7% (Fig. 2) form the highest proportion of preventive maintenance costs.



**Fig. 2.** Structure of the costs of preventive maintenance of a 6Dg diesel locomotive [14].

The cost verification, done in the operation stage, initiated the measures undertaken by the railway carrier (PKP Cargo S.A.) in cooperation with the research body (Institute of Rail Vehicles, Cracow University of Technology) intended to improve the efficiency of the locomotive maintenance process by changing the measurements of intervals between the maintenance levels and the scope of maintenance activities. It was

assumed that the changes should correspond to the actual operating work and include advanced level of diagnostics and registration of the operating condition of modernised locomotives.

## 2.1 Development of operational database

During the period from the start of operation and the first repair at the P4 level, done after 24 480 mth or after 5 years, the modernised locomotives were monitored during their operation and operational data were gathered therein, concerning:

- their kilometrages in km/year and in km/day;
- time of operation in h/year and in h/day;
- time to failure;
- causes for the failure;
- duration of maintenance repairs;
- costs of maintenance repairs, checks and scheduled repairs.

The electronic information, which was gathered and processed, was formally recorded on a preliminary basis in Microsoft Excel. Universal failure codes were used comprising 7 locomotive systems and 30 subassemblies.

## 2.2 Formal requirements related to the maintenance system change

An assessment of the possibility to change the maintenance strategy should take account of formal and legal requirements under the law which applies in Poland, including:

1. Directive 2008/110/EC of the European Parliament and of the Council of 16 December 2008 amending Directive 2004/49/EC on safety on the Community railways) (OJEU L 345 of 23.12.2008);
2. Commission Implementing Regulation (EU) No 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment and repealing Regulation (EC) No 352/2009 (OJEU L121 of 03.05.2013, as amended);
3. Announcement of the Speaker of the Sejm of the Republic of Poland of 13 October 2017 on the promulgation of the consolidated text of the Act on Rail Transport (Dz.U. 2017 item 2117);
4. Regulation of the Minister of Infrastructure and Construction of 28 July 2017 amending the regulation on the general technical conditions for the operation of rail vehicles (Dz. U. 2017, item 1525) and other.

Further, it is necessary to include in the analysis the railway carrier reference documents, such as:

1. Safety System Management Book with the necessary procedures, primarily regarding an assessment of the technical and operational risks;
2. Maintenance system and technical/operational documentation for the analysed locomotive.

The analysis of legal conditions has shown that the current regulations do not allow for performance of inspections or periodic repairs of railway vehicles according to a strategy based on the actual state of vehicle assemblies and subassemblies (CBM technique). The structure of the maintenance plan for railway vehicles must be defined with fixed distance measurements expressed in kilometers and/or units of time.

### 2.3 Statistical analysis of the process of operation

On the basis of the operational data gathered by the railway carrier for 2009–2015, i.e. from the beginning of operation of a series of 121 vehicles, Table 2 comprises the average time of operation in mth/year and the average kilometrage in km/year of modernised 6Dg locomotives. Figures 3a and 3b present the histograms of these figures. The average annual kilometrage was found to be 23484,5 km/year, and the maximum figure does not exceed 35544,9 km/year. The average time of operation is 3916,5 mth/year or 78,3% of the figure assumed in the maintenance system documentation: 5000,0 mth/year.

### 2.4 Concept of changes in the locomotive maintenance plan

The concept of changes in the maintenance plan for the 6Dg type locomotive required, above all, the collection of practical knowledge from specialists engaged in the maintenance of rolling stock about the possibility to change the intervals between the maintenance levels and modify the scopes of activities in the Maintenance System Documentation (DSU). Additionally, the results of the theoretical analyses were used to identify the locomotive weakest elements from the viewpoint of the impact on the vehicle technical availability. The analysis used the Fault

Tree Analysis (FTA) with Monte Carlo simulation which is presented in papers [14, 18, 19]. One of the indices serving the purpose of selecting the most relevant elements was the ReliaSoft's Downing Event Criticality Index (RS DECI) expressing the percentage of downtimes caused by a particular locomotive assembly or subassembly in the total downtime figure [20]:

$$RS\ DECI = \frac{C_{NSDE}}{N_{ALLdown}} \cdot 100\%, \quad (1)$$

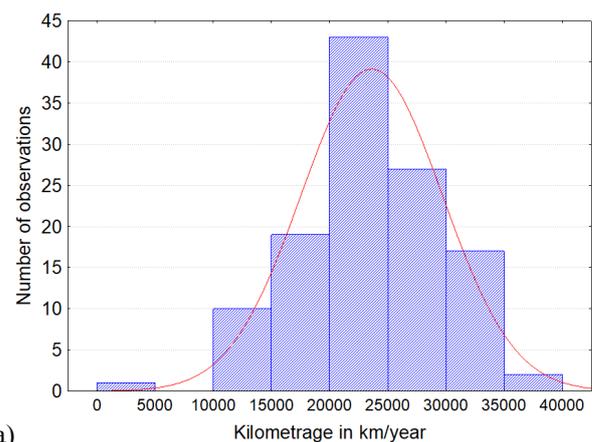
where:

$C_{NSDE}$  – number of downtimes caused by the particular locomotive assembly, subassembly;

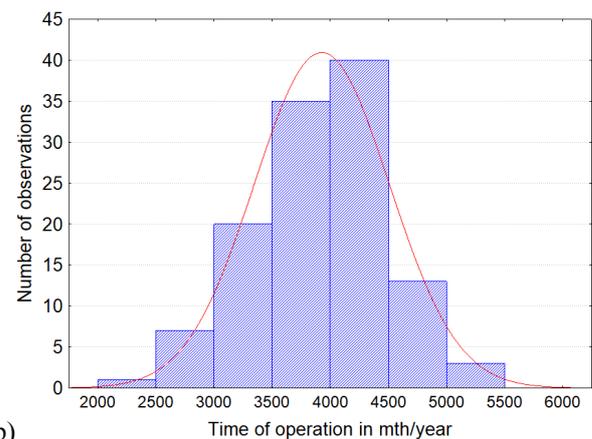
$N_{ALLdown}$  – number of all locomotive downtime.

**Table 2.** Statistical data on time of operation and kilometrage of locomotives of SM42 series, 6Dg type.

| Figure                      | Average | Total     | Min    | Max     | Standard deviation |
|-----------------------------|---------|-----------|--------|---------|--------------------|
| Time of operation, mth/year | 3916,5  | 466064,9  | 2492,9 | 5297,4  | 579,9              |
| Kilometrage, km/year        | 23484,5 | 2794650,5 | 3304,4 | 35544,9 | 6067,0             |



a)



b)

**Fig. 3.** a) Histogram of locomotives of the SM42, 6Dg type a) kilometrage in [km/year], b) time of operation in [mth/year] [14].

On the basis of the analysis, changes in the current plan for the maintenance of the SM42 series 6Dg type locomotives were proposed (Table 3).

**Table 3.** Current and proposed maintenance plans for 6Dg locomotives.

| No. | Maintenance level | Current                             | Proposed changes                    |
|-----|-------------------|-------------------------------------|-------------------------------------|
| 1   | P1                | 102 mth, 14 days,<br>1300 km        | 200 mth, 21 days,<br>2 500 km       |
| 2   | P2/1              | 510 mth, 25 days,<br>2500 km        | 1000 mth, 90 days,<br>10500 km      |
| 3   | P2/2              | 3060 mth, 5 months,<br>15000 km     | 3000 mth, 6 months,<br>21000 km     |
| 4   | P3                | 12240 mth, 20 months,<br>60000 km   | 18000 mth, 4 years,<br>100 000 km   |
| 5   | P4                | 24480 mth, 5 years,<br>200000 km    | 36000 mth, 8 years,<br>200000 km    |
| 6   | P5                | 122400 mth, 30 years,<br>1000000 km | 122400 mth, 30 years,<br>1000000 km |

### 2.5 RAMS analysis in the area of safety

The RAMS analysis in the area of safety was based on the results of the operational tests of a selected sample of 75 locomotives of the 6Dg type, operated by a railway carrier over a period of 15 months. This enabled the observation of the course of operation of the locomotives in different conditions thus providing creditable data for the reliability analysis. The reliability data were gathered in the IT system supporting the management of the means of transport, enabling precise registration of the Time to Failure (TTF) and the Time to Restore (TTR).

The RAMS indices relating to safety were determined for relevant elements, i.e. assemblies and sub-assemblies of locomotives, whose failure results in hazards to the reliability and safety of railway operations (so-called hazardous failure). On the basis of the analysis of operation data for the locomotive sample tested over the 15-month period, a total of 151 failures were recorded which were qualified as hazardous ones. This is approximately 30,6% of the total number of failures. The structure of the hazardous failures is as follows [14]:

1. Running gear:
  - 1.1. Failures and wear of the wheel outer contour – 3,6%.
2. Brake system (pneumatic and mechanical parts):
  - 2.1. Failures of main or auxiliary compressor – 5,5%;
  - 2.2. Failures of pneumatic conduits – 2,4%;
  - 2.3. Failures of pneumatic valves (inter alia, main or auxiliary valve of the driver, reducing, end, safety valve) – 3,4%;
  - 2.4. Failures of elements of the brake (e.g. levers, couplers, coupling pins, bushings, couplings, brake blocks) – 1,2%;
  - 2.5. Failures of the actuator in the brake system – 0,4%;
  - 2.6. Failures of the engine driving the main or auxiliary compressor of rail vehicle – 0,6%;
  - 2.7. Failures of other elements of the pneumatic circuit – 2,0%.
3. Vehicle drive safety control devices:
  - 3.1. Failures ABP (SHP, CA, RS), metering device (speed meter, ammeter) or radiotelephone – 10,4%.

In the RAMS analysis of the 6Dg locomotive, the following safety ratios were determined:

- a) FH(t) distribution function and the mean time to hazardous failure (MTTHF);

- b) Mean time between hazardous failures, MTBHF and MDTHF;

- c) Frequency of hazardous failures H for locomotive assemblies and subassemblies.

The definitions of the above ratios are available in specialist writings on reliability, availability, maintainability and safety, e.g.: [14, 21, 22] and in the applicable standards:

- PN-EN 50126:2002 Railway applications. The specification and demonstration of reliability, availability, maintainability and safety,
- PN-EN 61703:2016-12 Mathematical expressions for reliability, availability, maintainability and maintenance support terms.

### 2.6 Analysis of the risk involved in the proposed changes

The principles of the Common Safety Method (CSM) concerning risk analysis are described in Commission Implementing Regulation (EU) No. 402/2013 [23]. The detailed algorithm of the risk management process is presented in the Appendix to the Regulation entitled “Risk management process and independent assessment”. The procedure of risk qualification where changes are made in the maintenance system requires:

- analysis of the relevance of the proposed changes,
- hazard identification and development of a register of hazards,
- assessment of risk acceptability.

In accordance with the Regulation, the acceptance of the risk concerning the assessed system is tested using one or several of the following risk acceptance principles:

- use of codes of practice,
- use of a reference system,
- explicit risk estimation.

In the analysed case, following the procedure for identification of hazards and risk assessment of the Safety Management System applied by the railway carrier operating 6Dg type locomotives, the risk was qualified using the (Failure Mode and Effects (FMEA) Analysis. The FMEA method is a quantitative one in which the risk of hazard occurrence is estimated using the Risk Priority Number (RPN) [22].

The analysis demonstrated a possibility to make changes in the plan for maintenance of 6Dg type locomotives without breaching the accepted safety level and introducing entries in accordance with Table 2. Nonetheless, the changes in the maintenance plan required the development of additional safety measures concerning the assemblies and subassemblies of major importance for rail traffic safety: wheel sets, brake system, bogie support and frame.

### 2.7 Assessment of the effectiveness of the changes in the maintenance process

The effectiveness of the changes in the 6Dg locomotive maintenance plan was assessed on the basis of a comparison of the costs of preventive maintenance (PMC), which was expressed through the formulae (2) and (3), taking into account the costs of checks and repairs

of the 2017 level [11]. The calculations were based on the mean time of locomotive operation of 5 000,0 mth/year.

$$PMC_t = \sum_{i=1}^n PMC_i, \quad (2)$$

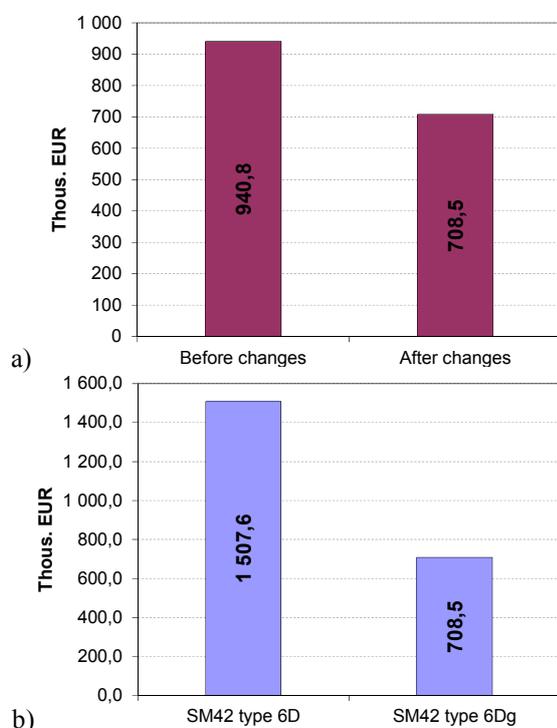
where  $PMC_i$  is costs of preventive maintenance in the year  $t$  for the maintenance level “ $i$ ” in EUR:

$$PMC_i = PMCL_i + PMCM_i = NPMA_i(t) [(MMH_i \cdot CPH_p)] + ACM_i, \quad (3)$$

where:

- $PMCL_i$  – the costs of labour for maintenance level “ $i$ ”;
- $PMCM_i$  – the costs of materials and spare parts for maintenance level “ $i$ ”, EUR;
- $NPMA_i(t)$  – number of preventive maintenance activities at maintenance level “ $i$ ” in a year of operation;
- $MMH_i$  – mean labour intensity of preventive maintenance at maintenance level “ $i$ ”, man-hours;
- $CPH_p$  – cost of man-hour in preventive maintenance:  $CPH_p = 13,71$  EUR/man-hour;
- $ACM_i$  – average cost of consumption of materials in preventive maintenance at maintenance level “ $i$ ”, EUR.

It was concluded on the basis of the calculations that as a result of the change in the maintenance strategy the costs of maintaining the modernised 6Dg type locomotive calculated in the full maintenance plan were reduced by 24,7% or EUR 232300,0 (Fig. 4a). For the entire series of 121 modernised vehicles owned by the carrier, the maintenance cost savings are EUR 28,1 million. In comparison with the unmodernised SM42 6D locomotive, the maintenance costs were reduced by 53,0% or EUR 799100,0 per vehicle (Fig. 4b).



**Fig. 4.** a) Comparison of the costs of preventive maintenance before and after the change in the maintenance plan, b) Comparison of the costs of preventive maintenance of a non-modernised 6D locomotive and a 6Dg modernised one after the maintenance plan change [14].

### 3 Conclusion

The costs of maintenance are the second, following the costs of power or fuel consumption, dominating cost category in the Life Cycle Costs LCC of railway means of transport. Hence, projects undertaken by rail carriers to enhance the efficiency of the process of vehicle operation by changing the maintenance strategy are fully justified. The methods presented in the paper are based on many years of experience from research and development work related to the change in the strategy of maintenance of traction vehicles and rail carriages. They indicate the important role of the RAMS analysis in the area of safety thus enabling proper classification of hazards, quantification of the frequency of their occurrence and adoption of appropriate criteria for risk assessment.

The considerations presented in the paper are of general relevance. They may be applied not only to rail vehicles but to other technical objects, which are subject to a complex maintenance system.

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