SAFETY OF OPERATION AND MAINTENANCE ACTIVITIES OF ROLLING STOCKS BY THE EXAMPLE OF ELECTRIC MULTIPLE UNITS EN96

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Resume

This paper deals with importance of executing maintenance activities of rolling stocks by the example of the electric multiple unit EN96 series and with influence of repairing rolling stocks on the transport safety. It also discusses Poland's Supreme Audit Office report for the 2017 year that concerns the condition of safety of the rail transport in Poland. It describes the way in which the maintenance operations are performed with a division of the maintenance levels that depend of time of utilization and distance travelled by a vehicle.

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1 Introduction

The physical condition of rolling stocks is a very important factor that affects the railway traffic safety. The necessity of performing regular maintenance operations comes from the reason that technical objects are subjected to inevitable wear processes. To prevent malfunctions that can lead to accidents on the railroad, periodic inspections are carried out. In the case of the electric multiple units, such as EN96 series vehicles, requirements of these inspections are included in the Ordinance of the Minister of Infrastructure of October 12, 2005 *On general technical conditions for the use of railway vehicles*. It also includes a list of other documents that describes term of technological and organizational conditions about exploitation of rolling stocks (for example relevant technical specifications and standardization documents, The Regulation concerning the International Carriage of Dangerous Goods by Rail - RID, Regulations concerning the International Haulage of private owner's wagons by Rail - RIP). The concept of operational maintenance of the rolling stocks is defined as organizational and technical activities that are designed to provide safe and economical utilization of technical objects as a part of a given transport service organization, as well as the part of the maintenance plan and applied maintenance level. The maintenance plan is a plan of projects and intensions of such elements as [1]:

- a range and types of inspections and services of rolling stocks;
- a range and frequency of operations that are connected with a preventive maintenance process, whose mainly purpose is to diminish probability of occurring a failure;
- a range and frequency of activities that are connected with a repairing process after declaration of inability of the whole rail vehicle or just its part to operate as intended;
- operations that result from specific maintenance conditions;
- the maintenance level of rolling stocks.

The main purpose of the paper is to present a description of maintenance operations of rolling stocks with the emphasis on safety of these operations, based on the previously created technological process for the EN96 series electric multiple unit. The article presents a comprehensive overview of the maintenance of rolling stocks in Poland. The proper performance of such operations is one of the factors for increasing safety in the rail transport.

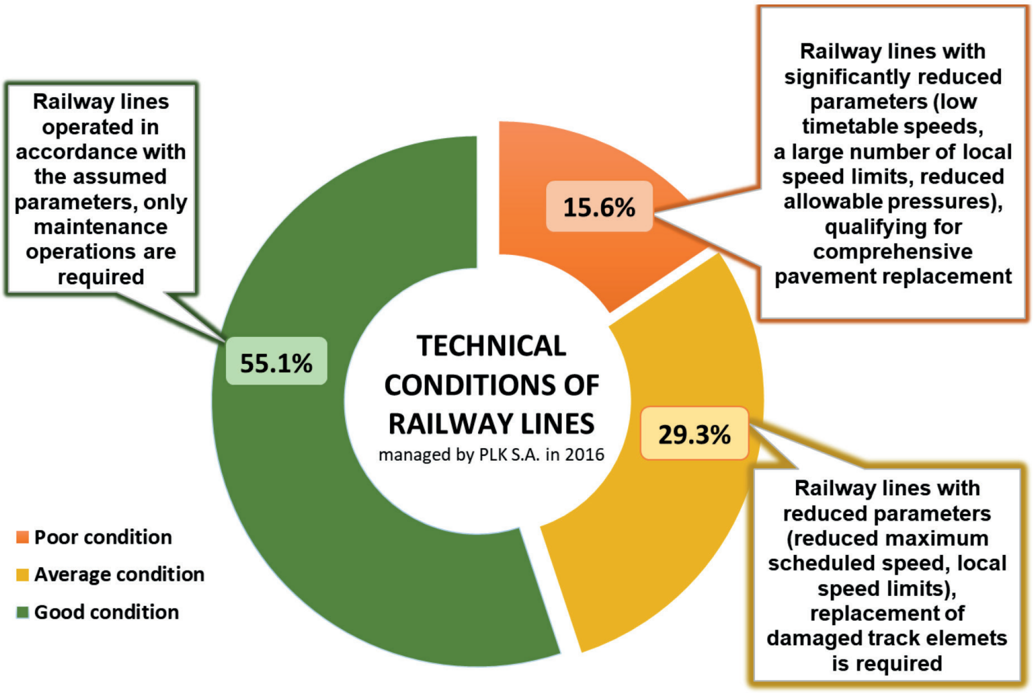

Figure 1 *Technical conditions of railway lines in 2016 [2]*

2 Railway traffic safety in Poland

Technical efficiency of the rolling stocks is one of the basic components of railway safety. The other elements are technical efficiency of the point and line rail infrastructure, transport organization, staff competence and experience, as well as implementing of proper anti-accident legal acts. All the entities involved in the transport process should follow these rules. These entities can be as follows [2]:

- executive entities such as:
  - ❑ railway infrastructure managers,
  - ❑ railway siding users,
  - ❑ railway carriers,
  - ❑ plants and workshops dealing with the maintenance processes of the rolling stock vehicles,
- supervising and controlling entities:
  - ❑ Office of Rail Transport,
  - ❑ State Commission for the Investigation of Railway Accidents,
  - ❑ Ministry of Infrastructure and Development.

The Supreme Audit Office report from 2017 shows that in comparison to 2014 significant improvement in the rail traffic safety did not occur. In the years 2010 - 2014, the railway safety level was very low in comparison to other Europe countries. It was determined not only by poor technical conditions of the rail infrastructure and rolling stock vehicles, but by multiple errors in a transport organization as well and by insufficient protection of transported commodities and passengers from criminal activities. However, the rail transport is still one of the safest means of the land transport with a constant decrease in number of serious accidents year by year. This report, which is concerned with the biggest national railway infrastructure managers, railway stations and 23 biggest rail carriers in Poland, shows the following conclusions [2]:

- the Number of railway accidents has decreased from 638 in 2015 to 581 in 2016, as well as the number of death tolls from 228 in 2015 to 169 in 2016;
- the number of individuals hit by the rolling stock who passed through the railroad in unauthorized places has decreased;
- in the years 2012 - 2016 there was a decrease in crimes committed inside the rolling stocks or in the rail area, such as stealing packages (by 16%), stealing other people's property (by 64.5%), extortion and robberies (by 57%) and beatings (by 72%).

The report discovered improprieties in 23 railway track development and construction units that are responsible for the railway lines in Poland. This led to a significant decline in the safety level of the railway traffic. The reason of this incongruities was, among others, unreliable performance of the line infrastructure maintenance tasks, as well as maintenance of the rail traffic control and monitoring equipment, which is a crucial factor to safety (in the 2017 year 1044.6 km of rail lines were in operation). Another reason was a lack of the radio-stop system encryption. This system is used to prevent the rail accidents. Encryption of this system should be introduced in 2023. The average age of a rolling stock vehicle is also high - for freight carriages - 27 years, for passenger carriages - 26 years and for locomotives - 32 years [2].

Many unused rolling stock vehicles limit utilization possibility of the railroad tracks for maneuvering purposes. Another factor that decreases safety is a lack of the formal settlement of obligations related to passenger carriage, electric rolling stock vehicles maintenance processes similar to one that regulate freight carriages - MMS System an EMC system. Another problem is a great diversity of types and series of carriages that are in possession in the biggest carriers. This makes difficult for unification and specialization of vehicles maintenance processes. The lack of relevant permissions for the Railway Protection Service to perform tasks included in the Polish Railway Transport Act from 2003, in the case of an event that requires intervention, also causes the low safety level of the rail traffic. Moreover, the railway stations are not considered as a part of the linear infrastructure in the Polish Railway Transport Act, which means that they are not included in the railway Safety Management System (SMS). Another root of the problem is that the PKP PLK S.A. (Polskie Koleje Panstwowe Polskie Linie Kolejowe) still uses the railway lines in a bad condition status and many of the railway platforms are not adjusted to the EU Regulation [3] in the terms of the height and distance of the platform edge from the railway line axis. More than 15% of used railway lines are classified for replacement (Figure 1). This has a major impact on the travel time of rolling stocks. The Supreme Audit Office requested PKP PLK S.A. to develop and implement a program to modernize these railway lines as a part of the company's own supervision [2].

The paper [4] describes the conditions and development of a safety criterion to prevent derailment of rolling stocks. The problem of preventing vehicle derailment should be considered as early as it is possible - at the design stage. Both during the testing and during operation, this is an essential factor for qualifying a vehicle for operation. If it is not met, there is no need for other tests (such as brake tests, strength tests of individual rolling stock components and dynamic tests). The safety criterion against derailment was introduced in 1908 as Nadal's formula and it is still used today to assess the safety of rolling stocks. An assessment of the vehicle's safety against derailment is determined from Equation (1) for the maximum ratio of the leading force Y to the vertical force Q. These forces take variable values when the vehicle is moving. The formula for the safety ratio is as follows:

$$\frac{Y}{Q} = \frac{tg\gamma - \mu}{1 + \mu \times tg\gamma}, \tag{1}$$

where:

γ - angle of inclination of the wheel flange,

μ - friction coefficient between wheel and rail.

After many tedious calculations, focused on selection of the optimal wheel profile, it was assumed that the angle of inclination of the wheel flange for the majority of rolling stocks should be 70 degrees. With a coefficient of friction of 0.36, the safety factor can be calculated - it should not exceed the value of 1.2. In summary, the author of the paper points out that too strict requirements result in a significant increase in vehicle manufacturing costs, high maintenance costs of railway infrastructure and low competitiveness of rail in relation to other modes of transport [4].

In [5] authors presented selected constructions of devices designed to increase passive safety of a rolling stock. These are various types of collision-absorbing elements designed for wagons-tanks, which meet the regulations of UIC (fr. Union internationale des chemins de fer - The International Union of Railways) cards. Development of material engineering and modern construction methods has an increasing influence on the properties of these elements. However, authors also point out the economic aspect - introduction of modern materials and methods will be associated with increased costs.

The safety aspect of rolling stocks also involves adapting the infrastructure to modern high-speed rails. Authors of [6] describe the technological process of adopting the main track and track-bed by using modern machines. On the CMK (Central Railway Main Line in Poland) lines, which are part of European high-speed rails, vehicles will be able to travel up to 250 km/h. Therefore, that imposes the high quality requirements for infrastructure preparation.

Another aspect of the railway traffic safety is an adequate control system. With development of the railway, those systems have improved technical solutions. Devices of the system are [7]:

- stationary equipment,
- rail locking systems,
- rail-road crossing protection systems.

When the physical conditions of such systems worsens excessively, they need to be renewed. Otherwise, damage will occur, which may cause a significant breach of their structure and result in a safety hazard. Due to the need to maintain an appropriate level of the railway traffic safety in Poland, systematic inspections of the physical condition of used railway traffic control devices are carried out. Authors of paper [7] point out that in most cases during the inspection in 2016 the conditions of these devices were unsatisfactory.

The rail transport is one of the safest modes of passenger transport. In the paper [8] the author, draws attention to the statistics of the rail accident mortality. In relation to train-kilometers, Poland is at the second place among countries with the highest mortality risk in the EU. It amounts to 1.5 fatalities per million train-kilometers, when the European average is 0.31. In relation to passenger-kilometers, Poland is at the 8th place with mortality rate of 0.5 victims per million train-kilometers. The European average is 0.16.

The paper [9] assesses the general physical conditions of rolling stock vehicles in Poland. It was stated that despite its constant improvement (which is the result of EU funds and projects implemented in cooperation with them) there are still many problems affecting safety of the rail transport in Poland. The author mentions, among other things, problems with obsolete rolling stock vehicles (30-40-year-old locomotives and wagons not meeting safety requirements). He also compares the physical condition of rolling stock vehicles in Western countries and mentions the difficult access of the new carriers to rolling stock in Poland, as well as the lack of an appropriate purchasing strategy for the new rolling stock vehicles.

Table 1 *Rolling stocks maintenance levels*

maintenance level	tasks characteristic	protocol	execution frequency
P1	checking or monitoring actions performed before the rolling stock goes on the line, after leaving it or while driving. most of the activities can be performed by employees of the carrier	1. assessment of the condition of main assemblies, subassemblies and other systems that have impact on driving safety 2. provision of the rolling stock spare parts 3. replacement of the fast-wearing assemblies and parts during operation	3000 km or 4 days
P2	actions to prevent exceeding wear limits they are performed in specialized workstations during the technical breaks between planned utilizations	1. detailed evaluation of the rolling stock physical condition by inspection of its circuits, examination of components without dismantling and diagnostic tests described in documentation 2. repairs performed by replacing standard components	30 000 km or 60 days
P3	actions to prevent wear limits from being exceeded they are performed in specialized workstations and with excluding the vehicle from intended exploitation	1. detailed evaluation of the rolling stock technical condition by inspection of its circuits, examination of components with dismantling and diagnostic tests described in documentation 2. planned subassembly replacements and small functional assembly repairs that are performed in specialized workstations	210 000 km or 13 months
P4	repair maintenance operations performed in specialized workstations	1. detailed physical condition verification of assemblies and subassemblies included in technical documentations, combined with their dismantling 2. planned replacement of assemblies and subassemblies 3. planned repairments of assemblies and subassemblies performed in specialized workshops	1 100 000 km or 5 years
P5	actions that improve the rolling stock conditions	1. dismantling of assemblies and subassemblies from the rolling stock and their replacement with new or regenerated parts 2. modifications to body of the rolling stocks and gearbox systems	3 300 000 km or 15 years

3 Rolling stocks maintenance levels

According to the guidelines included in the Ordinance of the Minister of October 12, 2005 *on general physical conditions for the operation of railway vehicles*, five levels of the rolling stocks maintenance can be distinguished [1]. They differ in time of performing tasks and in degree of their complexity. Although 15 years have passed since the guidelines were introduced, they are up to date and there is no need to amend them, as they are universal. Table 1 presents maintenance levels of rolling stock and description of maintenance operations that are covered in this Ordinance [1].

Paragraph 2 of [1] defines maintenance levels as a list of maintenance operations performed for a given rolling stock. Realization of this task requires proper technical equipment of the rolling stock maintenance point, relevant employees' qualifications and the proper certification range. Performing particular maintenance level depends on the distance travelled or the service life of the rolling stock. For each of them a technological process is created in which a list of performed maintenance tasks are included. It also contains a list of documents involved, a list of all the tasks that are outsourced to other workshops, a sketch of the rolling stock maintenance point, a list of specialized workstations, a list of relevant personnel competence and skills and required safety precautions. There is also the rule that during the performed maintenance activities from higher level, activities from lower levels should be executed as well.

Moreover, it is required to perform seasonal inspections twice a year. They are designed to prepare the vehicle and all its assemblies and components for changed weather conditions. In the event of malfunction during the normal exploitation, the vehicle should be delivered for repair outside the normal maintenance cycle. The main purpose of this repairment is to reinstate the physical conditions before the malfunctioning. During this repair, documentation and procedures from maintenance level P4 and P5 should be applied.

4 EN96 series electric multiple unit

An electric multiple unit is a railway rolling stock vehicle designed to transport passengers. It consists of:

- assemblies,
- subassemblies,
- elements that can be connected into circuits and systems.

Figure 2 *EN96 during course*

EN96 series 34WE vehicles are the two-part vehicles manufactured and constructed by PESA Bydgoszcz S.A. in 2011. The EN96 is a railway literal code and 34WE is a construction code. Those vehicles were constructed on behalf of the Marshal's Office of the Swietokrzyskie Voivodship in the amount of 4 units. Each of the vehicles has an assigned number EN96-001, EN96-002, EN96-003 or EN96-004. All the units were painted to white-grey. They are called ELFs (ELF - Electric Low Floor) and they are operated by Przewozy Regionalne sp. z o.o. Swietokrzyskie Department with headquarters in Kielce [10]. The EN96 series vehicles were designed to operating in a local passenger transport between big urban areas and in a suburban passenger transport. Their construction was adjusted to high and low rail stations (in the range of 300-960 mm). The vehicle consists of two parts - A and B, it was adapted to operate by two workers and its operating speed is 160 km/h. It could be powered with direct current 1.5 kV/3 kV as well as 15 kV/25 kV AC. The vehicle has two drive bogies and one rolling bogie. A modular body allows to freely arranging the multifunctional spaces - for example a bar corner, space for transport bicycles, bigger luggage [11]. It has 107 standing places and 123 sitting places. Driver's cabs are equipped with ergonomic remote panels and driver's assistant seats, fire extinguishers and air conditioning. Cabins are separated by doors from the passenger compartment. The passenger compartment is equipped with vandal-proof, permanent seats, luggage racks above the seats and handrails. Each part of the vehicle is heated by the floor convection heaters mounted under the seats in special covers. The heat is supplied by two heating and air conditioning units. There is one pair of entrance doors. The vehicle is powered by four asynchronous electric motors with a total active power of 1600 kW. The vehicle has two pneumatic braking systems [10]:

- indirect action pneumatic brake functioning as an emergency brake - it is a classic pneumatic brake, controlled by distributor valves by changing the pressure in the brake cylinders;
- direct-acting electro-pneumatic brake, functioning as the vehicle's main brake, used during its normal utilization. Braking power is regulated from the driver's desk and it depends on the actual operating conditions. Electrodynamic brake is supported by a pneumatic brake or all the braking power could be transferred to the electro pneumatic brake.

The vehicle is equipped by automatic coupling and spring devices for dampening. Powder fire extinguishers are located in the driver's cab and in passenger compartments. The fire protection meets the requirements of the Polish Standards and UIC cards. The vehicle is presented in Figure 2.

5 Safety of maintenance operations performed during technological process on the example of electrical multiple unit EN96

Paragraph 6 of [1] contains information that the maintenance of a vehicle should be performed by entities with qualified staff and by using of relevant technical infrastructure. It is important to provide organizational conditions that guarantee the correct performance of the tasks specified in the maintenance system documentation. Article 14a of [12] describes that each vehicle, before being released to utilization, must be assigned to an entity responsible for its maintenance. According to [13] it could be a railway enterprise, owner or an infrastructure manager. Its objective is to provide the safe vehicle transport by using the maintenance systems. To that purpose, this entity uses own workshops or other with whom it has a contract. Vehicle maintenance is executed according to:

- documentation, which contains maintenance processes for each vehicle,
- requirements that are in force such as maintenance standards and TSL (Transport-Spedition-Logistics) provisions.

Degree of complication and advance of maintenance activities in technical processes depends of individual

Table 2 List of tests performed in accordance to the P3 maintenance level

no.	test name
1.	pneumatic system tightness test
2.	the main, auxiliary and parking brake tests
3.	anti-slip traction control test
4.	rail current collector test
5.	air conditioning system test
6.	heating system test
7.	lighting system test
8.	vehicle control systems test
9.	dead-man's vigilance device test
10.	radiotelephone and radiostop test
11.	drive system test
12.	static break and pneumatic system tests
13.	leak tightness test
14.	test drive

maintenance process. In the case of the P3 level assemblies and subassemblies that should be reviewed as follows [10]:

- complete electrical multiple unit - this applies to maintenance operations related to the general condition of the vehicle,
- rolling stock frame,
- body and internal equipment;
- bogies,
- traction motor,
- automated coupling,
- rolling and drive wheelsets,
- brake and pneumatic systems,
- axial gear,
- heating,
- air conditioning for the passenger compartment and for the driver's compartment,
- drive system,
- cooling system of traction motors,
- pantograph,
- doors,
- sanitary equipment and water installation,
- batteries,
- electrical multiple unit systems.

In addition, the auxiliary equipment such as transport trolleys, pullers for dismantling the axle boxes and multimeters, are used. In the case of the P3 maintenance level list of tests are shown in Table 2.

The EN96 vehicle maintenance activities of the P3 level are carried out at a given rolling stock maintenance point at the following workstations [10]:

1. Brake tests workstation,
2. Repair and inspection workstation of rolling stocks in the tent hall.
3. Assembly and disassembly track with an inspection channel,
4. ABP equipment workstation.
5. Workstation for checking the vehicle axis geometry and for grinding the vehicle,
6. Workstation for repairing mechanical speedometers,
7. Workstation for air conditioning repair and maintenance,
8. Workstation for repairing electric and electronic devices,
9. Workstation for analyzing saved vehicle's operational parameters from electronic recorders,
10. Workstation for performing welding operations on vehicles,
11. Workstation for washing and cleaning the rolling stocks,
12. Trackside dead-man's vigilance device checking workstation,
13. Workstation for lifting the rolling stock boxes,
14. Workstation for regulating lighting of the vehicle front,
15. Workstation for washing bogies and other components,
16. Workstation for testing safety valves, pneumatic and electro-pneumatic devices,
17. Battery charging station.
18. Workstation for repairment of current collectors and electric machines,
19. Locksmith's workstation,
20. Workstation for on-board monitoring recording analysis and
21. IT and control workstation.

In order to perform the maintenance operations safely, the rules contained in the technological process for a given vehicle must be strictly observed. All the necessary precautions are listed, as well as special equipment and relevant repair workstations, according to which all the processes should be carried out. Not all of the maintenance activities are performed at the particular rolling stock maintenance point. Some assemblies and subassemblies require specialized equipment and devices that maintenance points do not have either for economic reasons or for need for the special staff qualifications. Hence, these activities are outsourced to external entities and documents concerning this operation are included in the maintenance process. Test reports are also included in this documentation and the entire process should be carried out in accordance with them. During the inspection-repairing operations, the staff are obligated to [10]:

- use the personal protection equipment,
- abide by rules of Occupational Health and Safety.

Inspection and repair tasks should be preceded by securing the vehicle from the uncontrolled rolling and in the case of operating on pneumatic systems, pressure in these systems must be reduced to the atmospheric level. Regulation of brakes should be performed after completion of work on the chassis and tests of vehicle systems must not be performed until other inspection were not be finished. During the operation, the rolling stock workers should pay particular attention to equipment and devices that are essential to traffic safety. An important aspect that greatly affects safety is monitoring the state of wear of given parts, assemblies and subassemblies in order to determine whether the maximum wear limit has not been exceeded. Parts that are especially prone to exceed the wear limit are [10]:

- rolling surfaces of wheelsets,
- pneumatic systems, their tightness,
- brake blocks,
- bumper suspension devices.

In documentation, provided with the vehicle, there is also a list of subassemblies that are under special technical supervision performed by the Office of Technical Inspection. Those are elements such as air tanks, safety valves etc. The basic requirements for performing maintenance operations by the personnel is a good knowledge of the technical documentation and maintenance systems, as well as a proper training for operation and maintenance of a given rolling stock. These maintenance operations must be carried out by qualified staff e.g. welding tasks should be performed by workshops that are certified according to the Polish Norm PN-M-69009 and employees performing the non-destructive testing should have at least the level 2 qualification in accordance with the PN-EN 473:2002 [10].

6 Technological process P3 of EN96

The technological process for a rolling stock should be performed in accordance with the maintenance system documentation. For the EN96 series vehicles, documentation is provided for employees of the headquarters of Przewozy Regionalne sp. z o.o. and for employees of the rolling stock workshops. The technological process based on design, whose author is Przewozy Regionalne sp. z o.o., consists of the following elements:

- introduction,
- guidelines for the technological process creating,
- change sheet,
- list of related documents,
- situational sketch of the rolling stock maintenance point,
- list of specialized workstations,
- list of personnel,
- performed maintenance activities,
- list of outsourced operations,
- process of acceptance of performed maintenance activities,
- required safety precautions.

Introduction and guidelines for creation of the technological process describe the basic requirements of the technological process. The change sheet should be filled in each case of change to the process. List of related documents contains a list of all the documents that are related to the technological process. Another element of the technological process is a situational sketch of the rolling stock maintenance point. In the case of Przewozy Regionalne sp. z o.o. Swietokrzyskie Department, the rolling stock maintenance point is located in Skarzysko-Kamienna. The sketch contains the workstation layout and a diagram of the track system. The next item in documentation is a list of tools and equipment that are used in the process. The other item is a list of specialized stations with a detailed description of each of them. The list of employees should include the necessary competences of employees and the required number of them that are involved in the maintenance process. The most important element is a list of performed maintenance activities. Then, there is a list of outsourced operations, the process of acceptance of performed operations and required safety precautions. Execution of maintenance process of the rolling stock vehicles is performed in accordance with specific chains of action, known as algorithms or procedures. Each process starts with a description of a specific vehicle, an identification of assemblies and components and possible damages or malfunctions that are not involved in the specific maintenance level process. Maintenance activities start with cleaning assemblies and components, carrying out diagnostic tests, verifying and inspection of the parts concerned, as well as issuing the work instructions. Issuing of instructions concerns the repair of individual components and assemblies, regeneration of certain elements, as well as installing new parts in case of scrapping up the old ones. Once assemblies and components are installed, they must be tested to assess their proper functioning. If the inspection was negative, the repair cycle should be repeated; in the case of a positive inspection, the components should be mounted on a vehicle and a running test should be carried out. Then, if not no additional malfunctions occur, the vehicle is put into service. In each step, the proper documentation should be filled out. Figure 3 presents an example algorithm that describes in general the technological P3 process. This algorithm was prepared according to the EN96 documentation and [10].

The process is carried out every 210 000 km or 13 months of exploitation. This ensures that the technical efficiency of a vehicle is maintained. Its proper performance is crucial for operation safety and, from a practical point

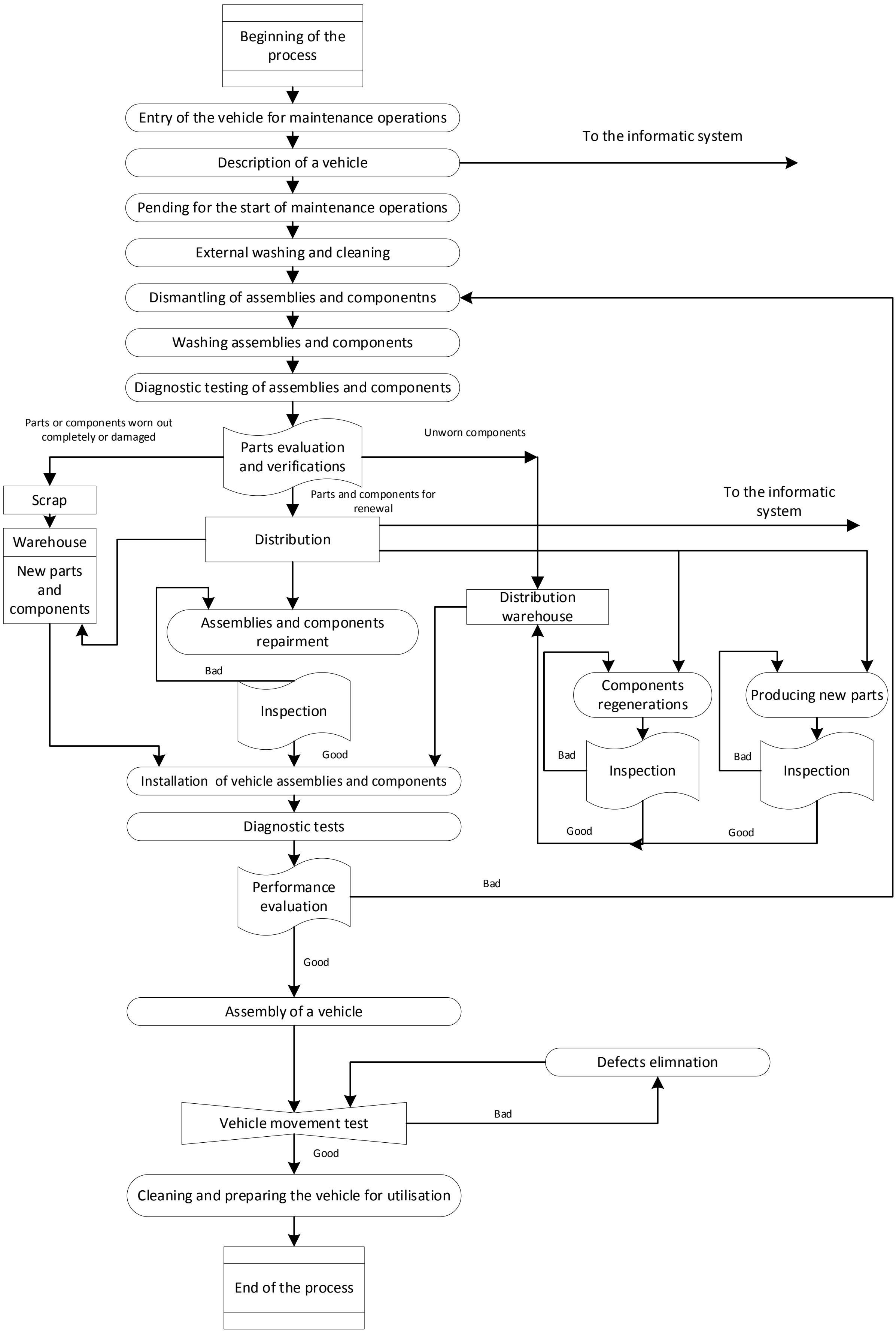

Figure 3 *Algorithm of the technological P3 process*

of view, prevents expensive consequences of unexpected malfunctions. The rolling stocks transport heavy and large loads, which means that their reliability is very important. Breakdowns of these vehicles are not frequent. However, their results can be severe.

7 Conclusions

Safety of the rail transport mainly depends of the physical condition of vehicles and the rail infrastructure conditions. Maintenance activities are performed to reduce the risk of a vehicle malfunction, which directly impacts the operational and rail transport safety, to a minimum. It is crucial to perform those operations in accordance with instructions included in the individual technological processes. The 2017 Supreme Audit Office's report states that the level of the rail transport safety in Poland is not sufficient and that there are many problems that must be eliminated. The most important problem is not the quality of performed maintenance operations but a poor rail line infrastructure conditions and a high age of utilized vehicles. Electrical multiple units of the EN96 series, that have been produced by PESA Bydgoszcz SA, are not worn out in comparison to other rolling stocks in Poland - there were first inspection and repair activities of the P4 level conducted, as well as many operational services that were designed to improve the vehicle's use safety. The P3 maintenance level, discussed in this paper, is a comprehensive vehicle inspection that contains a detailed check of its technical conditions and planned replacements of important vehicle components affecting its operational safety. Result of this paper is a design of an algorithm of the P3 technological process for the rolling stock maintenance. It shows the complexity of performing the maintenance operations that are crucial for safety of the rail transport.

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