

## Digitization of fleet maintenance systems as an option to improve the maintainability function

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### Abstract

The subject of this paper is a thorough acquaintance with the functioning of a complex Maintenance System - consideration of all influential parameters in Maintenance Processes, analysis of collected data and finally discussion on the Maintainability of the observed system and proposal for improvement using Digitization. As a Maintenance System (MS), we will be considering a transport company providing intercity and international bus transport of passengers. A proposal for optimization of certain processes within the observed MS will be presented at the end. The aim is to mitigate or completely eliminate the negative impact of the detected critical control points on the indicators of Maintainability of the observed system. The idea is to monitor the movement of workers in charge of maintaining bus engines and then, based on the recorded trajectory, make a proposal for new position of work tables and the optimal arrangement of parts needed for the specific maintenance activity. The movement of workers is recorded simply - by using ultrasonic sensors and adequate software to manage the collected data. That way, the trajectory of the worker during the maintenance operation is simplified which inevitably contributes to shortening the time required to perform the operation.

### Key words

maintenance system;  
data flow diagram;  
maintenance process;  
operative level of management;  
system effectiveness;  
maintainability;  
digitalization;  
workers' movement scheme;

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## 1. Introduction

A motor vehicle is considered as one of the most complex technical systems that is affected by a large number of different factors, which results in the occurrence of numerous failures. Possible malfunctions are one of the main causes that lead to failures and which impose the need to analyses how to eliminate them. Failure is defined as any event after which the system is unable to perform the specified target function. Given the complexity of the issue and the importance of its study, this area is under attention by all those involved in the field of motor vehicles, whether in the phase of development, production or use and maintenance. By adequate maintenance the required performance indicators are achieved, as well as success of performing the target function during its service life.

## 2. Maintenance strategies

The very concept of maintenance of technical systems is defined as:

Maintenance of technical systems implies the implementation of all measures necessary for one machine, plant or the entire factory to function in the prescribed manner, developing performance within the predefined limits, i.e. with the required performance outputs and quality, without failure and with the proper protection of the environment, and under the assumption of availability of all resources, i.e. with the necessary logistic support [1].

Based on the given definition of maintenance, one can see that maintenance is a complex functional system. In the engineering sense, the maintenance system can be implemented in several ways, in several

alternatives. Certain alternatives of the maintenance system, determined by the concept, organization and character of the maintenance procedure, as well as the relationship between the individual levels at which the maintenance is performed, are called maintenance strategies [1]. Figure 1 shows the components of the maintenance system, which mostly determine the applied strategy.

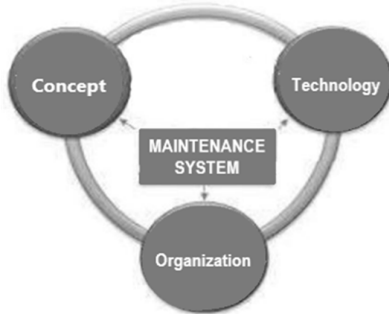


Figure 1. Maintenance system components [1]

### 3. Overview of the observed maintenance system (MS)

The MS observed through this paper is a transportation company that is present on the market of transport services in intercity and international traffic. It has a fleet of 70 buses. The fleet is heterogeneous and consists of vehicles of several brands. An average age of a bus is 5 years. A maintenance system is a set of elements that ensures that the necessary procedures for maintenance of a technical system are carried out in the required manner, under given conditions and at a given time interval [7].

Figure 2 shows a fleet maintenance process management flow chart. Three levels of management (strategic, tactical, operational) and mutual relations are presented. The operational level is represented by DF (Data Flow) diagrams.

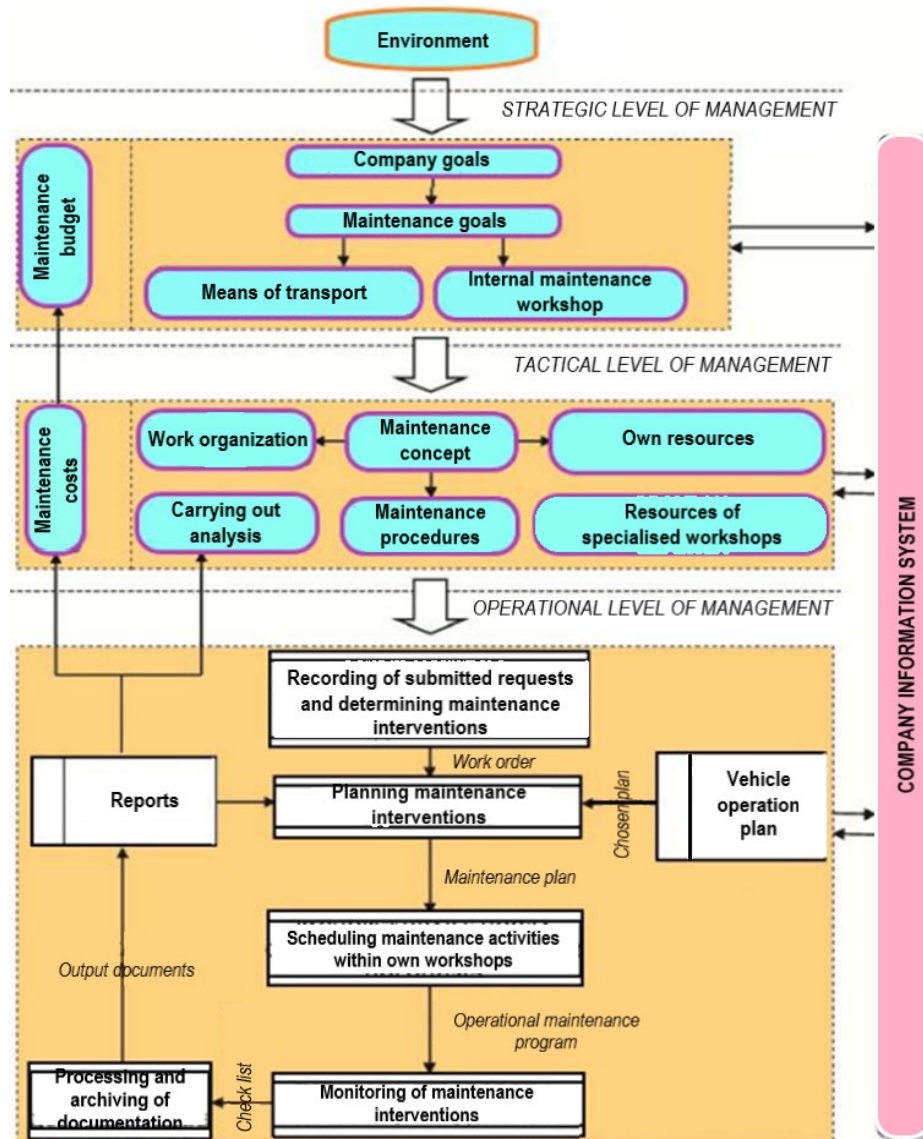


Figure 1. Fleet maintenance process management flow chart

At the strategic level, the business goals of the company are defined, as well as the assets that are maintained. The starting point at the tactical level of management is the analysis of processes, performance and equipment in the company. In addition, this level of management defines the maintenance policy, i.e. the concept, resources, organization, and the degree of outsourcing. **The operational level of management** includes activities for planning, implementation and control of maintenance work, as well as assessment of the efficiency of the maintenance process using key indicators of system performance [5]. The emphasis of writing this paper is focused on the operational level.

Within the operational level of the maintenance process management<sup>12</sup>, daily issued requests for maintenance after the report of a fault or the stated need for maintenance are recorded. A maintenance request can be made based on:

- preventive maintenance plan according to the number of kilometers travelled (e.g. for the driveline system),
- the driver's observations of changes in the vehicle's driving behavior (e.g. brake system noise),
- checks during the daily inspection (e.g. tire damage),
- occurrence of sudden failure during the performance of transportation.

The result of the implementation of maintenance work planning activities is a "Maintenance Plan (MP)". It is a document that is a basic tool in management the fleet maintenance process [2]. The method of measuring the time that elapses from the moment when the defect is found until the moment when the failure removal starts in the observed MS is implemented using this document (Table 1).

Table 1. Example of a "Maintenance Plan" and how to measure the time that elapses from the moment when the defect is found until the moment when the defect rectification starts

MAINTENANCE PLAN									
Vehicle identification number	Place of intervention	Kilometers travelled [km]	Planned/relised beginning of maintenance intervention		Maintenance activity	Workers	Spare parts	Planned/relised completion of maintenance intervention	
			Date	Time				Date	Time
V9	Own workshop	257 483	14.09.20.	12:30	Regular engine overhaul	2M	Engine oil, filters, drive belts, rollers ...	14.09.20.	16:30
			14.09.20.	13:00				14.09.20.	17:25
V51	Own workshop	320 840	16.09.20.	9:30	Repair of injectors	-	-	16.09.20.	14:30
			16.09.20.	9:45				16.09.20.	15:05
V17	Own workshop	205 944	18.09.20.	11:00	Engine diagnostics	1M, 1E	-	18.09.20.	14:00
			18.09.20.	11:10				18.09.20.	14:10
V13	Own workshop	213 662	22.09.20.	11:30	Coolant pump replacement	1M	Coolant pump	22.09.20.	15:30
			22.09.20.	12:15				22.09.20.	16:40
V22	Own workshop	126 577	24.09.20.	7:00	Regular engine service	1M	Engine oil, filters	24.09.20.	9:00
			24.09.20.	7:25				24.09.20.	9:30

For each recorded vehicle request for maintenance the MP contains the following information:

- time and date of the defect discovery or the need for maintenance,
- planned and accomplish date and time of the beginning of maintenance interventions,
- planned and accomplish dates and time of completion of maintenance interventions.

Table 1 gives an example of how to measure the mentioned time intervals in the observed MS, through the "Maintenance Plan". Maintenance interventions on "V9", "V51", "V17", "V13" and "V22" vehicles are planned to be performed in the internal workshops.

The process flow of regular engine maintenance and accompanying activities is shown via the DataFlow diagram (Figure 3). Observing the afore-mentioned

<sup>12</sup> The maintenance process is a set of procedures and activities that are carried out over time on technical systems in order to prevent the occurrence of failures or to eliminate them [6]. The maintenance process has the characteristics of a highly stochastic process. The stochastic variable is the operating time of the technical system until the moment when the maintenance procedure should be performed (determined by the reliability properties) and the time required to perform the maintenance procedure (determined by the quality of the maintenance system), in order to return the system from "state of failure" to "operational state".

diagram, certain critical points are noticed, as potential causes of interruption, i.e. reduction of the effectiveness of the system as a whole. The consequences of the delay are shown in Table 1. Based on the data collected by observing a number of maintenance processes (among which the data in the table are given as an example), a statistical analysis of the measured times was performed - next chapter.

Thereby the term system effectiveness means the probability that the system will successfully enter into operation and perform the goal function in the scheduled time interval and defined limits, in the

given environmental conditions [3]. Vehicles can be in a "state of failure" immediately after the request for maintenance. Therefore, the vehicles are unavailable for operation from the moment the request is made, until the moment when the necessary maintenance interventions are carried out. That is why it is important that, in addition to an efficient and high-quality implementation of the necessary maintenance interventions, the preparation and scheduling of the upcoming maintenance work will be done efficiently in order to return the vehicles to operating condition in the shortest possible time.

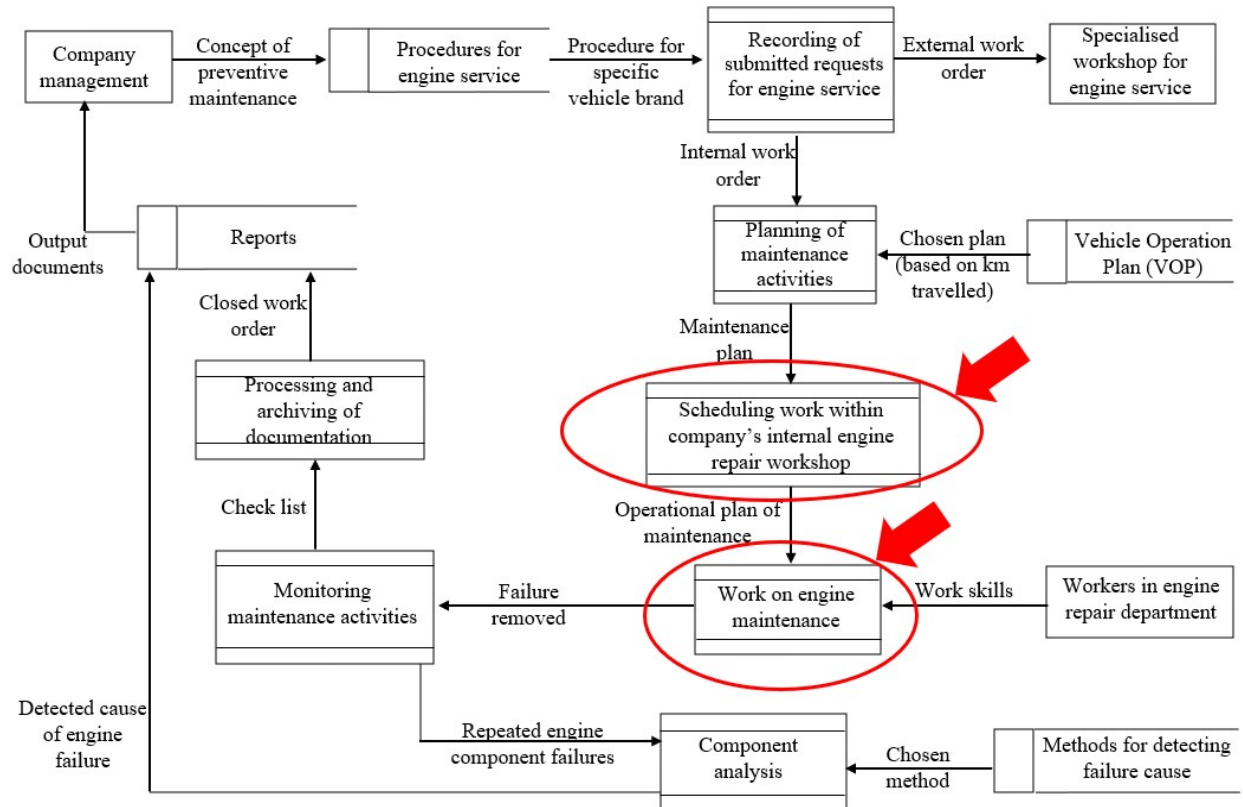


Figure 2. Engine maintenance process – DataFlowDiagram

#### 4. Statistical analysis of collected times

The following analyses were performed in the reference observation period (two working weeks):

- Comparative analysis of planned and realised beginning of interventions (Figure 4);
- Comparative analysis of planned and realised completion of interventions (Figure 5);
- Analysis of recorded maintenance requests within specific time intervals (Figure 6).

It should be noted here that the sample of 20 recorded maintenance interventions, in a relatively short time of data collection (10 working days), is small for defining general truths and bringing to adequate conclusions for the entire maintenance system.

The average delay time in relation to the planned start of maintenance work, according to the results from Figure 4 is 25 min. According to the data in Figure 5, the average delay in completing vehicle maintenance is 38 min. The diagram shown in Figure 6 presents the number of completed maintenance tasks, arranged by delay intervals - realized in relation to the planned end of the intervention. It can be seen that one intervention was performed in the first 15 min delay, as well as in the other (15 to 30 min). With a delay of 30 to 45 min, two maintenance interventions were performed, while one operation was completed with a delay belonging to the last interval (more than 45 min). At this point, it is once again noted that the sample of observed interventions is small in order to arrive at

conclusions that are more serious as a representative of the entire MS.

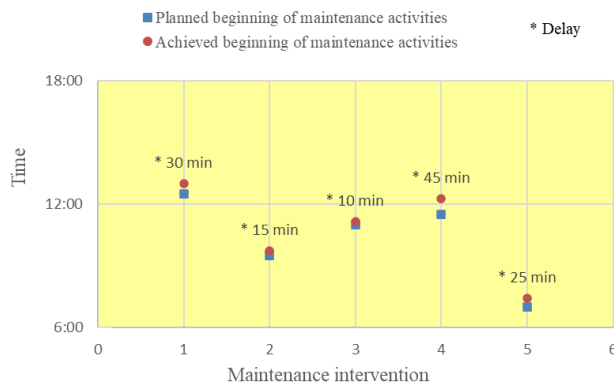


Figure 3. Comparative analysis of foreseen and realised times of beginning of interventions

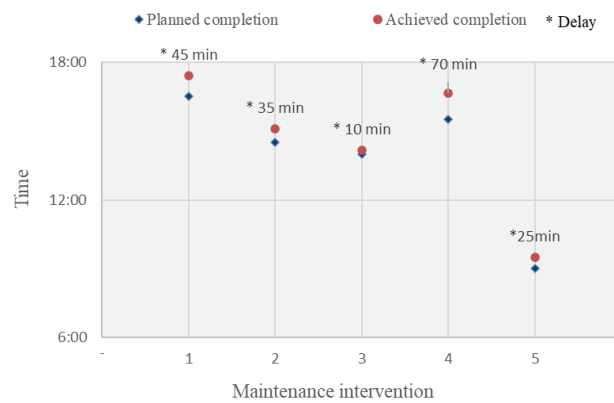


Figure 4. Analysis of the time that elapses from the moment when the defect is found or the need for maintenance until the moment when the defect rectification starts

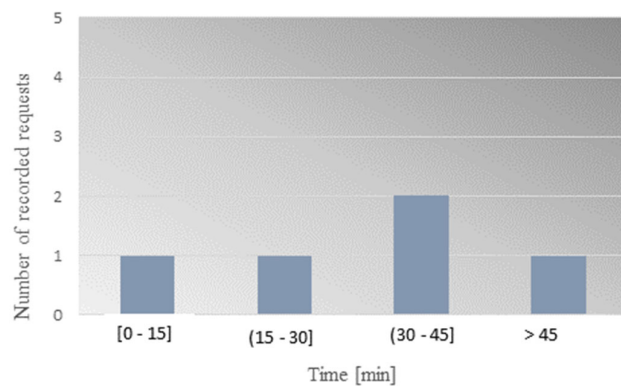


Figure 5. Number of recorded maintenance requests by time intervals

More expedient conclusions and assessments of the maintainability of the overall MS would be available after analysing all maintenance processes within the MS and observing a number of different maintenance interventions over a longer period. Maintenance system optimization can be performed in different ways, using mathematical models and empirical-heuristic methods. The increasing complexity of vehicles and the costs of their development highlight

the importance of reliability as an important factor in the quality of the fleet and its availability.

### 5. Conclusion on the maintainability of the observed MS (critical points)

Maintainability is defined as the probability that the designed maintenance procedure will be performed at a given time, given environmental conditions and at minimal cost. [4]. The maintainability is related to:

- the principle of simplicity of the structure of components and the convenience of their composition (assembly, disassembly, easy interchangeability, availability);
- quality of system construction;
- conditions for performing maintenance activities;
- level of integral system support of components.

The analysis of the collected data on delay times considered the contribution of individual processes to the efficiency of the entire MS (as one of the indicators of maintainability). As a result, two critical points were observed on the DataFlow diagram - highlighted in red in Figure 3:

- Scheduling work within company’s internal engine repair workshop
- Work on engine maintenance

These two activities within the process were identified as critical because they were recognized as the main factor in reducing the effectiveness of MS i.e. delays presented through the analysis in the previous chapter. Therefore, they represent potential activities that can be improved by applying digitization.

### 6. Proposal for improvement

A proposal for optimization of individual processes within the observed MS will be presented here. The aim is to mitigate or completely eliminate the negative impact of the mentioned critical control points on the main indicators of maintainability by applying digitization.

The idea is to monitor the movement of workers in charge of bus engines maintenance and, based on the recorded trajectory, present a proposal for a new position of worktables and the optimal layout of parts needed for the appropriate maintenance activity. This would inevitably contribute to shortening the time needed to perform the maintenance activity.

The way in which the described idea would be carried out implies the following:

- Installation of ultrasonic sensors for measuring distance in each of the corners of the workshop;
- Maintenance workers carry sensors (transmitters) in work suits and their movement inside the room is measured in relation to the reference sensors placed in the corners;

- Creating a workers movement layout using a software for collecting and processing data from sensor units (e.g. Marvelmind robotics);
- Analysis of the collected movement layouts (trajectory schemes) on a relevant sample, identification of critical points and drawing conclusions on optimizing the layout of the necessary equipment and parts. The equipment required to implement the proposed idea of improving productivity is given in Figure 7.



Starter set configuration:  
 1 mobile beacon – 99 €  
 4 stationary beacons – 4\*99 €  
 1 router - 99 €  
 All required SW included

Figure 6. Initial equipment package to implement the proposed idea [8]

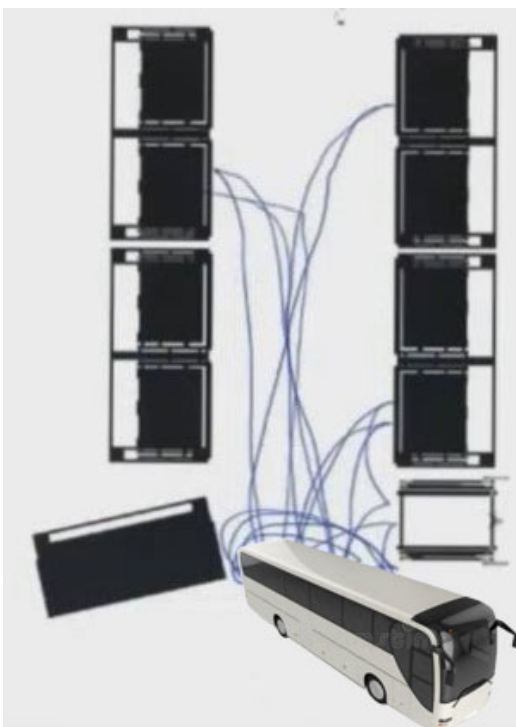


Figure 7. Layout of workers movement during the performance of regular engine service

In addition, the figure shows the prices of the devices shown. These devices work on the principle of ultrasonic signals. The signal range is up to 30 meters

(real conditions), i.e. up to 50 meters (laboratory conditions). Figure 8 shows an example of the scheme recorded with a digitized procedure for monitoring the movement of workers.

## 7. Conclusion

The result of applying procedure described in the previous chapter is an optimized layout of the required components (workbenches, spare parts, tools and accessories), which simplifies the trajectory of the worker during the maintenance activity and thus shortens the time required for its execution. This can be clearly concluded if we compare the layouts of workers' movement before and after the placement of components in the determined optimal positions.

By digitizing certain activities of the maintenance process, it is possible to reduce the time required for scheduling work within the workshop and the time for work on engine maintenance and completion of the maintenance activity. That way, the negative effect of the observed critical points is mitigated and the delay that occurs because of them is reduced. The importance of digitization, which results in an increase in the effectiveness of the system, is reflected in both the technical and economic aspects of the entire maintenance system. Therefore, it is important that digitization becomes an integral part of the fleet maintenance system. This ensures optimal management of the vehicle service life cycle and easier achievement of the set business goals.

## 8. Literature

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