NEW ASPECTS OF MAINTENANCE MANAGEMENT AND THE MATERIAL OF SPARE PARTS

VERA PELANTOVA[1], PETR CECAK[2]
Technical university of Liberec
[1]Faculty of Mechanical Engineering, KSA
[2]Faculty of Mechanical Engineering, KSA
Liberec, Czech Republic
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e-mail: petr.cecak@tul.cz, vera.pelantova@tul.cz

The ensuring of a continuity and a quality of the production leads a part of organisations to think about the status quo of maintenance of their equipment. The maintenance also depends on types of spare parts. The management often perceives only production characters. However, current knowledge points to a deeper interdependence. This article describes practical experience with maintenance issues. The relationship of materials of spare parts and the origin of nonconformities of a production is seen as a significant one and it puts these facts into context. The reducing of costs plays a role mainly in many organisations. This factor leads to the increase of nonconformities in spare parts themselves and elsewhere in organisations. This topic of the article is embedded in the context of knowledge from steps of example of implementationof the Industry 4.0 in the organisation. The result is several recommendations for organisations in the maintenance of the equipment.

KEYWORDS
Maintenance, spare parts, material,; Industry 4.0, innovation, production, organisation

1 INTRODUCTION

A classic device maintenance is common in many organisations. However, the future prosperity of organisations must continue to evolve. The maintenance is influenced by many factors at present. New directions of maintenance management must be presented, where a material of parts and also spare parts play an important role.

2 LITERATURE REVIEW ON THE MAINTENANCE MANAGEMENT AND NEW ASPECTS

The first it is necessary to know for a further consideration of its aspects, what narrower topics other publications are dealing with. Then, the look at several of them follows.

The study [Luca 2015] addresses the area of qualitative nonconformities in the automotive industry. The publication [Galeto 2010] tries to contribute to the strengthening of relationship between the future staff training and an organisational practice in the quality management. The article [Nour 2017] deals with the analysis of the change and improvement of the maintenance system. The article [Miszal 2014] examines the ability of connecting of employees to maintenance service in organisations. The study [Khajavi 2014] creates the relationship of supply chain and a computer technology to spare parts issues. The article [Huiskonen 2001] manages the logistics of spare parts in relation to the strategy. It describes links of characters of the spare part andof elements of the logistic string. The text [Burati1992] describes the cost of reprocessing and replacement of parts.

The model construction BOM (bill of materials) transformation with full specification including materials into the maintenance BOM is presented by the article [Liu 2014]. The analysis of life cycle costs on bridge constructions using polymer and carbon fibre parts and comparison with traditional materials, mainly steels, is performed by authors [Eamon 2012]. The article [Pulselli 2007]deals with the relationship between the use of materials and environmental aspects, especially in the engineering sector. The relationship between the characteristics of spare parts and the logistics system of the organisation is dealt with in the text [Huiskonen 2001]. The text [Kans 2016] links the Industry 4.0 conception with the maintenance of transport systems. The added value associated with the Industry 4.0 is showedby the article [Buzkova 2017]. The new role of a human in the Industry 4.0 is described in the article [Koukolik 2017].

The methodologies (the tool base) used to solving of these problems are interesting. The study [Luca 2015] uses a proven tool the Ishikawa diagram to analyse of causes. The publication [Galeto 2010] identifies factors that lead to a bad learning of the quality in relation to ISO 9001 standard [ISO 9001]. It uses Deming's ideas. Text [Joventic 2012] mainly addresses the improvement of the maintenance process on a created model. It uses the JIT method to support of the process approach. The document [Varzaru 2015] introduces a management system for a higher performance of the organisation and sets necessary quantified characters in relation to the strategy based on audit reports and using the 5S tool. The connection of mini-audit and the VSM tool is applied in the publication [Vavruska 2014]. The article [Nour 2017] refers to the availability of equipment and changes to maintenance procedures. The article [Miszal 2014] points to a pro-customer behaviour, which in the organisation means a comfortable equipment and a strengthening of the awareness of the influence of the employee on the outcome of the organisation. The maintenance must be planned. The study [Khajavi 2014] introduces de facto distributed spare parts production, which is based on the development of possible supply chain configuration scenarios and with it associated operating costs. The study [Khajavi 2014] models inventories and applies learned lessons in organisational practice to differentiate of the policy of different spare parts. The text[Burati1992] uses historical data. The text [Kans 2016] recommends self training courses for staff, especially in the maintenance. The work of operators should be diverse and interesting according to the article [Buzkova 2017]. The article [Koukolik 2017] highlights the need for a higher intelligence in the conflict with sophisticated systems. It requires the autonomy of thought. The text [Huiskonen 2001]also solves the location of materials in the logistics system.

Problematic areas of the topic are these. There are a number of different nonconformities. These nonconformities are shared by the study [Luca 2015] on manufacturing, given by an industrial area and by a poor service. The publication [Galeto 2010] sees nonconformities for example such as the use of the wrong management tool, unnecessary action and especially the punishment of employees who have saw these errors. It is necessary to lead employees to an integrated thinking. The text [Joventic 2012] measures the cost of non-quality. The article [Miszal 2014] emphasizes the need to track the response time of anequipment failure. It is even connected with the reliability of the equipment maintenance and the satisfaction of the employee with the work. The study [Khajavi 2014] points to shorter production cycles, cheapness and autonomy of distributed production and supply of spare parts. According to the text [Buzkova 2017], the digitisation is also advantageous for ordinary employees. The article [Pulselli 2007] takes into account the non-renewable energy sources, the waste and the

exhaustiveness of materials even in relation to technological processes.

However, the maintenance management also faces a number of problems. It continues with the wrong way of teaching and does not relate to facts across scientific disciplines, how it would have, according to the publication [Galeto 2010]. The text [Joventic 2012] has little data on model testing and simplified management. According to the document [Varzaru 2015], strategic goals and characters are changed and components are unnecessary, old or badly placed. Often, data from the past are also missing. In addition, there is not unifying department for production, maintenance and logistics. The article [Nour 2017] points out to the problematic geostrategic reality and the need to link maintenance to it. Employees have the awareness of problems of the equipment and they waited for production tools, according to the article [Miszal 2014]. This article recommends a common training for production and maintenance employees, but it was applied from approximately 1/3 of cases. The notcompliance of maintenance leads to an employee frustration. The study [Khajavi 2014] has problems with difficulty of employees, slow production of parts and investment in equipment, because it spoils the implementation of a distributed production of spare parts. The study [Khajavi 2014]calls for cooperation stakeholders on the creation of components. The article [Buzkova 2017] recommends learning from nonconformities, because it does not happend common yet.

Aspects of maintenance management outline these findings and present the future trends of researches. The connection of networks of systems, intelligence and control is mentioned in the text [Galeto 2010]. The document [Varzaru 2015] proposes to reduce unplanned stopstates of equipment, establishingof critical equipment and it plans to reach the target during 5 years. The article [Miszal 2014] provides a quick response to disturbances, available tools and workable equipment and safety workplace environments. The study [Khajavi 2014] also points to the safety. The modelling of maintenance costs helps to determine areas of the future research in the text [Burati1992]. The text [Kans 2016] shows a clear direction to the Industry 4.0. An advanced diagnosis is used that initiates maintenance itself. The human is the most important part of the chain according to the article [Buzkova 2017] and the maintenance must to be a predictive and the energy must be usedfrom renewable sources. The article [Koukolik 2017] recommends an appropriate motivation of employees. Results of the article [Eamon 2012] show cost savings by using new materials. The article [Liu 2014] leads to a more efficient maintenance documentation.

The study [Khajavi 2014] recommends to expand itself model for example for different settings of production configurations, low downtime and so on. Furthermore, it recommends to compare different production methods for low production volumes and to model of different production configurations. The article [Koukolik 2017] recommends to explore the issue of the implementation of the Industry 4.0 in organisations in the Czech Republic. The article [Pulselli 2007] writes to continue in the research of the relationship between materials and the environment.

3 DISCUSSION ON THESE PROBLEMS

The main aspect of maintenance development will be and it is already the Industry 4.0, how can be seen above.There is obvious with regard to the Industry 4.0 conception, that the training will be need on technical, management and organisational side. The improvement is necessary. Spare parts in a long supply chain mean a more expensiveprice of them and a longer delivery time. An insufficient item description (specification of characters) can mean a different delivery, its different function and consequently a customer dissatisfaction. Alternatively, it can be perform a reworking or re-order a spare part or a material, because these elementary parts are the core for whole system. The literary review brings the ongoing development of new materials. They are usually new types of plastic, but it is also experimented with metallic powders and on the basis of atoms of chemical elements themselves. This way creates new properties and functions of components. Just new materials often mean an environmental burden and the need for precaution. The Industry 4.0 conception also shows itself as a complex in terms of the maintenance. The development of a new maintenance is well underpinned by the Czech Society of Maintenance in the Czech Republic. This fact is presented for example by following two publications. The book [Legat 2013] in a wide extent presents this fact and this topic also covers. The article [Zajicek 2015] deals with the maintenance of a seemingly simple backup system, which supports a security aspect. The publication [Galeto 2010] points well to often mistake practice of a quality education that affects maintenance and from this reason goes against the process approach, what is a bad. Deming's ideas are very much needed for the current situation. All of management tools and Production Planning and Control methods mentioned here can be connected together in a process unit. An internal customer environment, as in the text [Miszal 2014], is not described. Maintenance applications in full scope are appropriate. The Industry 4.0 will be a very sophisticated system that is still developed. The understanding of conception this matter does not exclude.It is suitable for the maintenance. Studies, such as the text [Miszal 2014], highlight connection of a quality maintenance and an equipment operator, are valuable, because they show this interconnection. In a similar spirit, there is an information about punishment of employees for warning of nonconformities, as in the article [Galeto 2010], which are rather given in the background. However, it strongly helps to the occurrence of further nonconformities. The pressure on material savings, component saving and now energy savings are also important, as in the publication [Pulselli 2007]. There is also a problematic relationship among departments of maintenance, production, quality and logistics in organisations in the Czech Republic. Nonconformities and accidents, as a source of safety instructions, must be taken seriously. These facts have the influence on paradigm applications, such just as the Industry 4.0 conception.

According to the article [Koukolik 2017], the issue of the implementation of the Industry 4.0 conception will be examined in relation to aspects of maintenance management in the organisationin this article.

4 PILOT PROJECT

The relationship between claims of production and maintenance of equipment in the organisation is not negligible. It can be argued that the underestimation of maintenance goes hand in hand with an increasing of the production of nonconformity components. Organisationstry currently to maximize reduce production costs and by simply way to reduce a budget of the maintenance in the organisation. The maintenance is therefore forced to purchase cheaper non-original spare parts. (They are not from the original manufacturer). The purchase of these non-original parts leads therefore to their reduced quality (for example the original part has a lifetime of 50,000 hours and a cheaper non-original part has a lifetime of 30,000 hours). Unfortunately, such a maintenance approach is not unique and it repeats in many organisations.

This article presents a pilot project with research of the status quo of themaintenance management and an example of the first stepsof implementation of the Industry 4.0 conception.
This article extends the pre-study according to the text [Cecak 2017].It expands acquired knowledge, addresses some other aspects, more deals with materials of spare parts.It adds further insights from the continuation of this practice and further experience from other four organisations from authors of this article. This study was conducted in organisations in the Czech Republic. The number of employees in the first analysed organisation is 160, thus it is a medium size organisation. The organisation operates in the field of mechanical engineering and it has a serial production. It has a hierarchical functional structure and own maintenance department.Other organisations are also small to medium enterprises and they operate in fields of automotive (1), of electronic engineering (2) and of service (1). They have a piece and a serial production. The maintenance is often a part of the production department (in 75% of a researched sample).

	Number of NO [Pieces]	Produced[Pieces]	Mismatch[%]
2013	12430	2189686	0,57%
2014	8881	2310537	0,38%
2015	10385	2268652	0,46%

Figure 1. A percentage of nonconforming products (NO are spare parts), originally based on the publication [Cecak 2017].

All researched organisations havea preventative maintenance and maintenance after a break according to the type that applies to machines and preparations. The maintenance department of researched pilot organisationhas its own specialized SW, which also solves the availability of spare parts.

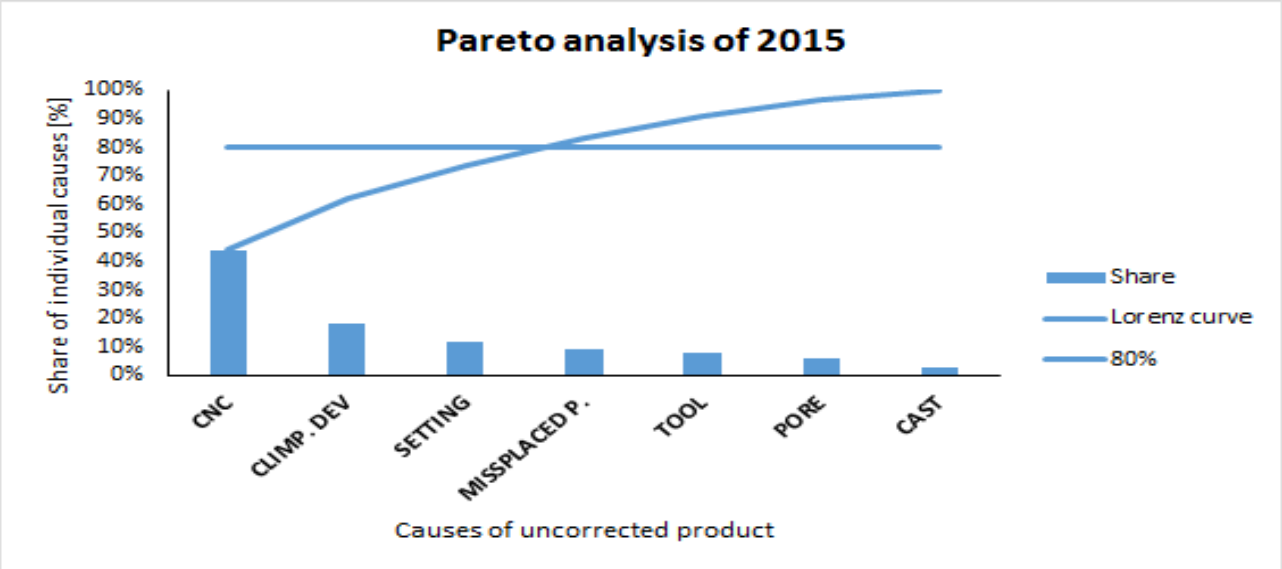

Figure 2. The Pareto analysis of one example of the year, originally based on the publication [Cecak 2017].

Only half of other organisations has some SW for maintenance. The stock of spare parts and materials in pilot organisationis organised under maintenance, which speeds up its work. This stock is a part of main stock including a production matertial and spare parts in other organisations.

The pilot organisation has more significant data about relation of maintenance, nonconformities and costs.As input data for the initial data analysis, Separator Booksof pilot organisation were used, in which the head of the check department recordsall nonconforming parts from the organisation's production process. The production process of the organisation consists here of four operations of machining of castings. The main technology process is used the milling. The organisation uses production machines of own construction, what is not usually in other organisations. The pilot organisation provided data for 3 years. All nonconforming products are written in the Separator's Book with following parameters: date, product, number of NO pieces, setter, employee (worker), operation and machine.
A percentage representation of nonconforming products in total quantity of production of the organisation was determined for finding out of the gravity of analysed problem. It is shown on Figure 1. The goal of the organisation in the documentation is to reach a 0.2% limit of nonconforming parts in the total amountunder the existing conditions of the substantial neighbourhood.A part of other organisations has not so long data (approximately 50%), this way specified characters or similar goals.
It can be seen from Figure 1.that the organisation does not reach of its goals for the representation of nonconforming parts in the total amount. Therefore, it is necessary to focus more on this issue and to analyse in more detail causes of origin of nonconformities in the production of the organisation. The Pareto analysis (as Figure 2.) with parameters of cases of nonconformity origin (machine, tool, preparation, casting, workpiece error (mistake of employee), and adjustment) was performed.
This project of the article deals with CNC errors, tools, preparation and adjustment. The financial aspect of the maintenance is a very important from a managerial point of view and therefore it was determined here. The total financial difficulty for produced nonconforming parts by this way was calculate for a better visualisation. Prices were determine from the base of individual prices of raw castings given products. The price presented in Figure 3. is the total price for all 3 years.

Causes	CNC [KČ]	TOOL [KČ]	CLIMPING DEV. [KČ]	SETTING [KČ]	SUMARY [KČ]
Cost	894236	228474	307027	344144	1773881

Figure 3. Costs of uncorrected parts, originally based on the publication [Cecak 2017].

Total financial costs of nonconformity parts are not negligible. Total costs climbed to proximally1 775 000CZK during 3 years. Explored causes were reduced on CNC, tool and preparation problems after meeting with the top management of the organisation.

Root causes must find of these nonconformities for removal of cases of origin of nonconformity parts. Further, the Ishikawa diagram was assembled for separation of individual causes.

A cause consequential chain was used to the determination of partial root causes. Thanks to this chain, individual root causes were determined, which were subsequently evaluated according to their severity, the number of nonconformity parts and an elimination severity.

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The biggest problems of the cause consequential chaintaking into account of maintenance issues in other organisations (which are similar) are following:

- The lifetime of components of equipment is not monitored.
- The maintenance has not repaired the preparation.
- The status quo of the tool is not being monitored.
- An inappropriate system of component maintenance of the equipment was realised.

Other nonconformities relate to maintenance relationships to a production department and a quality department, a low maintenance position in the top management thinking, very limited financial options for maintenance and a time pressure from other departments of the organisation to the maintenance.

For these reasons, but not only from them, the project was focused then on the following machine components**.** They are common in equipment at many organisations. The preparation error for a high complexity and a variability of individual manufacturing preparations was nor solved. There are a list of researched components:

- Spindle
- Liquid management pumps
- Liquid economy
- Ball screw

The design of actions with using the Industry 4.0 aspects is described below in the text.Complete solution of sensors using for machines´ components was solved for implementation of preventive maintenance in this part of the project. Sensors of characters of machine components quantities have been selecteddue:

- Online monitoring of the status quo of the component.
- Minimizing of the influence of a human factor
- Immediate detection of a fault
- The accuracy of results
- Possibilities to forecast the future development of component independently of the expected lifetime.

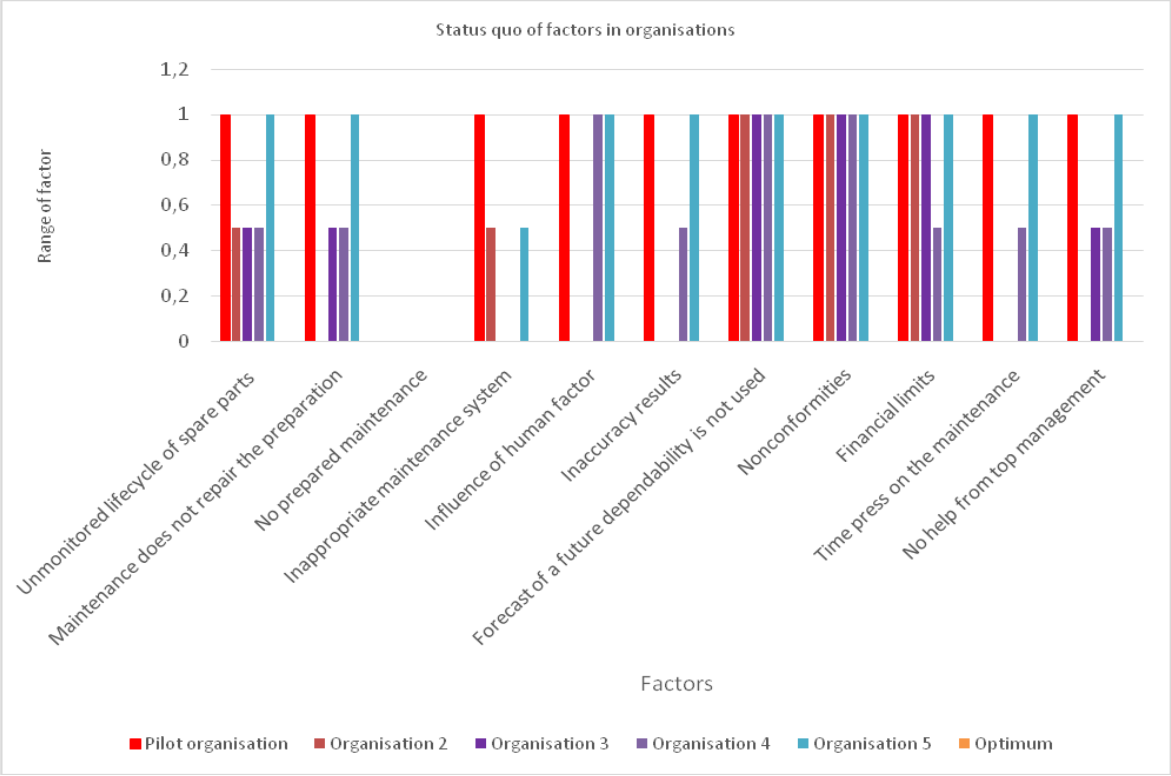

Figure 4. Factors, which are limited the Industry 4.0 in the sample of organisations, own of the author Pelantova.

The comparison of factors, which are poorly limited the Industry 4.0 in researched organisations here, is presented in Figure 4. It outcomes from the list of these factors, which is a result of the observation of maintenance in organisations.

Proposal of solving of the monitoring was created for each machine component.

The spindle as an important component was solved this way. The solution using of accelerometers on the first spindle bearing was designed to monitor lifetime of spindle. This bearing is a critical part for machining accuracy. For this reason, and to reduce a financial complexity of the overall solution, it is necessary to fit this bearing with the

accelerometer.
An accelerometer signal is sent on a special evaluation unit, which send on the signal to the PLC, which is located on the machine (equipment).
The spindle lifetime monitoring is the first of the project, because there is the highest number of defects in nonconforming parts. This problem occurs not only for the reasons mentioned above, but also due to the choice of a wrong type of the spindle. This way inappropriately realised spindle selection such as a highspeed spindle choice with ceramic bearings for a fine machining with a low material picking instead of the choice of forced a lowspeed spindle with conventionalbearings for machining cast iron with high material picking. This fact results in increased wear out of ceramic bearings or even to a machine failure due to breakage spindle. For these reasons, it is indispensable for correctlychoice spare parts of machines, madefrom suitable materials for the application.
Pumps of a liquid economy was solved this way. The pump of cooling system pump and the hydraulic pump of the machine can be counted into the machine's pump of the liquid economy. For these pumps two different solutions of status quo monitoring have been proposed.
The first solution is to use a temperature sensor. This solution is based on a direct measurement of the surface temperature of the pump thatincreasing of wear out of blades of the pump causes a friction and this way also the surface temperature increases.
The second solution is to monitor a direct measurement of electricity consumption. This solution is based on the assumption that a more worn out pump will have also in a higher power consumption. The measurement of direct power consumption can be used in other applications in the organisation. One of the other possible applications is the possibility of the recalculation ofa consumed energy to the core temperature of the electric drive. Another possible application is also the use of measured consumption values to reduce the energy difficulty of the organisation. For this reason, this solution is a qualitative better than the previous proposed solution, because it offers more applications for measured values.

The liquid economy management was solved this way. There flow measurement by line was proposed to monitor the leakage of a fluid line. Such measured values can also be used as monitoring of the status quo of pumps. This solution has been designed to management ofa hydraulic fluid and a coolant fluid. It is therefore necessary to purchase 3 + 3 flowmeters in this example. It is also necessary to purchase a special evaluation unit for each flow meter, which then sends the measured data to the PLC.

The ball screw was solved this way. The solution with the use of accelerometers on each bolt was proposed to monitor the lifetime of ball screws of the machine. With this tool, additional data can be obtained to check of the status quo of setting of the machine and of the spindle. Two types of machines are used in the organisation, with the horizontal axis of the spindle and with the vertical spindle axis. These types of machines do not have the same number of ball screws, so it is necessary to divide these solutions into two groups.

After these parts the linking and the visualisation was proposed. The transmission of data from physical characters sensors to the autonomousweb application is provided by a set of evaluation units (for each sensor one unit), PLC (for each machine) to a shopflor computer or a central computer. This data path is shown in Figure 5.

Two ways of data from the PLC to the web application were proposed for a maximal safety of the system. The first way (main) goes from the PLC to the central computer and then subsequently from it to the web application. Back way via shop floor computer was created to ensure a continuous flow of data for the web application.
The visualisation of measured data is ensured by the web application, which is created in the SCADA application. This web application is divided into two parts. The main page of the application has the possibility of choice of the machine. The second part helps with the visualisation of monitored characters.

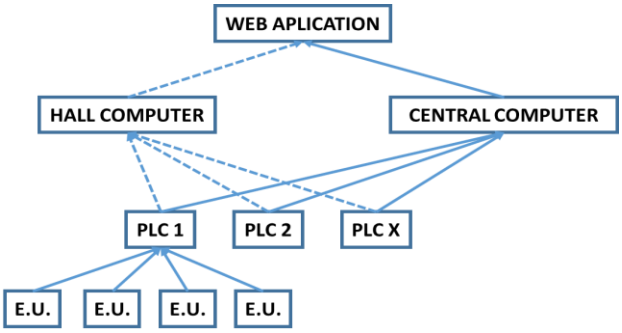

Figure 5. Data path, originally based on the publication [Cecak 2017].

Precise technical specifications and identifications of used sensors and other parts and materials are not provided here due to internal limitations in the organisation. However, it is included in the organisation document.
In addition, the following recommendations can be established:
- The assent and a real support of the top management of the organisation with the implementation of conceptions such as the Industry 4.0 to enhance a performance and an efficiency and a reinforcement of soft factors.
- To identify a basic automation and diagnostic features for a current support of the production department and also the maintenance department.
- To consider the originality of spare parts and properties of materials used to ensure a long serviceability of the equipment.
- To store and to analyze an old device maintenance data.
- To support employees in efforts to improve of the production and also the maintenance of equipment in the organisation and to the increasing of culture of the safety.

5 CONCLUSION

Aspects of the maintenance management are basically two main: a technical and a human. This article deals mainly with the technical aspect of the maintenance. The effort was on selected key spare parts of the device to introduce the problem of a sensor connection to enhance of the maintenance. This is the introduction of advanced diagnostics for the predictive maintenance. The design phase proved to be a feasible. It is also feasible to program the required SW to connect sensors on sensors of the machine and the computer system of the organisation. For the lifetime and the functionality of spare parts, the used material is significant. The priority has been given to classical materials by employees of organisations. Positive results of this study would be a saving electricity and a significantly reducing of the number of nonconformities not only in the maintenance and a more appropriate economy of spare parts.
This proposed solution in the article is a pilot project for implementing of the Industry 4.0 in the experimental

organisation. The total financial cost of this solution on all 21 machines of the organisation is over 7 000 000 CZK. Unfortunately, the top management of the organisation decided, after a detailed review and examination of the proposed variant, that the financial burden is unbearable for the organisation.Similarly, top managements of other observed organisations also express to install of sensors in equipment as the base of building of the Industry 4.0. On the other hand, it is necessary to consider, whether the price of sensors from suppliers is too high for the given market and whether their quality corresponds to requirements of these customers.

The human aspect thus gains an importance. The fundamental limit of this case study is de facto an incomplete introduction of full diagnostic due to decision makings of the top management. The high price of sensors and other elements is the second significant limit. The project also struck out of its boundaries with regard to other works and to the short time, which limited it.From this status quo the discussion can be open, whether it is a financially affordable for all organisation to implement the Industry 4.0. Large organisations that are direct suppliers to the automotive industry, have implemented such sophistically solutions already in place long time ago. However, unfortunately, small and medium-sized organisations still have other investment priorities, as for example gradual implementations of Toyota Production System method. These organisations prefer to implement cheaper monitoring options, as for example statistical methods for process control.Also a more rigorous categorisation of equipment into groups and a settlement of nonconformities in the maintenance in organisations would contribute also to a better management of the maintenance and its spare parts and materials. However, a study of types of materials in organisations is the subject of another publication.

In the future, it will be necessary to find a way to increase the motivation of both manufacturing and maintenance staff, because many of these employees are frustrated with an existing maintenance management and with interventions of the top management. All employees of organisations will need to train appropriately for new conceptions like the Industry 4.0. A consistent settlement of nonconformities is important for own management system of every organisation. Additional studies of the implementation of the Industry 4.0 in organisations will need to be done to ensure that enough knowledge is available and can be provided a further development.

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CONTACTS:

Ing. Vera Pelantova, Ph.D.
Technical university of Liberec
Faculty of Mechanical Engineering, KSA
Studentska 2, 461 17, Liberec 1, Czech Republic
Tel.: +420 485 353 520, vera.pelantova@tul.cz
www.tul.cz

Ing. Petr Cecak
Technical university of Liberec
Faculty of Mechanical Engineering, KSA
Studentska 2, 461 17, Liberec 1, Czech Republic
petr.cecak@gmail.com
www.tul.cz