BASICS OF DESIGNING MAINTENANCE PROCESSES IN INDUSTRY 4.0

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This paper deals with a new research of designing proactive maintenance processes for the Fourth Industrial Revolution, the so-called Industry 4.0. The mission and position of maintenance in a modern managed factory is highlighted by the fact that maintenance is one of the major processes that affect production productivity. In the near future, whatever is possible to digitize will be digitized, and anything that can be networked will be networked. Digitization is the key element for the future success of factories. Software is increasingly becoming a decisive production factor, because all of these networked machines must be controlled and all the digital data must be stored, processed, and meaningfully analyzed. Therefore, the successful companies of today (manufacturing and non-manufacturing) will need to be or become software companies, too.

KEYWORDS

maintenance, digitization, steps for designing, smart maintenance, technical service, systems designing

1 INTRODUCTION

Both, strategy and an overall maintenance policy, have an impact on performance of machines and devices. Productivity of production process, capital and investment returns and consequently the entire profit of companies all have a bearing on it. Maintenance policy must be conducted based on customer requirements in the area of quality, operational capability of machines and processes and operational reliability of machinery, which all have an impact on added value and costs. Maintenance activities become gradually perceived more and more as a key to economic success of manufacturing companies. This is a direct influence of concepts of manufacturing factory management, demanding new high standards of management. Industrial production of the new era will be highly flexible in production volume and customization, extensive integration between customers, companies, and suppliers, and above all sustainable [Shrouf 2014]. To be prepared for new requirements of the future posed by new concepts, we must ask questions about the present state, analyse the same and arrive with new concepts and new models of proactive maintenance systems. To accomplish this step, it is necessary to adopt proper management procedures in the area of maintenance and technical services as well. Regardless of the sophistication level any given organization operates at, gradual development of maintenance management and labor is a must if the goal is to provide excellent quality of equipment servicing. The country that will set the growth of its own competitiveness as its main objective, must unconditionally engage into the process of international distribution of labor. [Belas 2016]

2 WHAT IS THE PROBLEM

Key competences for maintenance, repair and overhaul (MRO) operators are permanent availability, a short respond time, continuous access to current information and real-time process monitoring for customers [Dietrich 2017]. Traditionally, maintenance is viewed as the necessary challenge that needs to be controlled and affordably reduced. Maintenance was once considered a necessary evil, but it is now being viewed as a key contributor to profit in a manufacturing or service providing operation [Rakyta 2016].

Many of the world's leading experts claim that the technological development in information and communication technologies (ICT) manifests an exponential growth. Humankind rapidly multiplies the amount of data generated. Therefore, we must look for new ways of how to obtain the necessary information out of all these data. The rapid growth of data volumes in the near future will be significantly driven by internet especially and its latest development, the Internet of Things. The turbulent market and global competition affect the requirement for shorting the innovation cycle [Micieta 2014a]. The way humankind will manage and make use of this new technology, will significantly influence its further technological and industrial development. The Internet of Things can become a new source of productivity growth and technological progress, but also the nightmare of humanity.

We see a problem here. On the one hand, information and communication technologies (ICT) and machines are very sophisticated. On the other hand however, many factories are not ready for transforming the standard maintenance into a smart one and subsequently into an intelligent maintenance. It is therefore necessary to carry out practical field research and to map the current state in manufacturing factories and their readiness for the fourth industrial revolution, the so-called Industry 4.0.

The basic information source for the designing is mainly a database from the technical preparation of the production [Krajcovic 2016]. In the first stage on their journey to Industry 4.0, many factories must start with rudimentary sensor installation onto critical machine parts, with collection of data provided by these sensors and with learning how to work with such data. Otherwise the fourth industrial revolution might result in the factories' bankruptcy. Digital implementation must be a continuous, not a charge-forward process. If basic principles are not understood, the subsequent development will not head in the right direction. The first thing the factories need to realize is that their data exist in a context. The Industry 4.0 triggers are, in our opinion, the following areas:

- the need to collect real data (and have them readily available in computers),
- data inaccuracy (bad data = bad decision making),
- objectivization, prediction and update of information.

The practical survey focused on contemporary state of maintenance and technical service in factories (Figure 1, Figure 2, Figure3 and Figure 4). These factories are from automotive industry (TIER1, TIER 2, TIER 3) in Slovak and Czech Republic. This article contains just basic information about digitization in factories, because a lot of information from implementation are secret (factories want competitive advantage).

For the purpose of this paper, the following answers have been selected and processed in graphs. The graphs show that the root causes of problems have not yet been removed, namely the insufficient or poor categorization of machinery or data collection. The majority of factories is not prepared for digital maintenance. On the basis of our survey, we described the problem formulation and its solution. The statistical sample is comprised of 72 factories.

Question one (1): Do you use the categorization of machinery into design functional units for scheduling preventive maintenance intervals and their optimization?

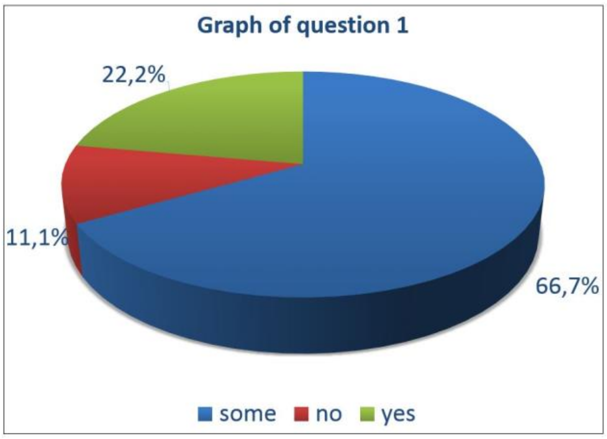

Figure 1. Graph of question one

Question two (2): Are you ready for transformation of maintenance into digital maintenance?

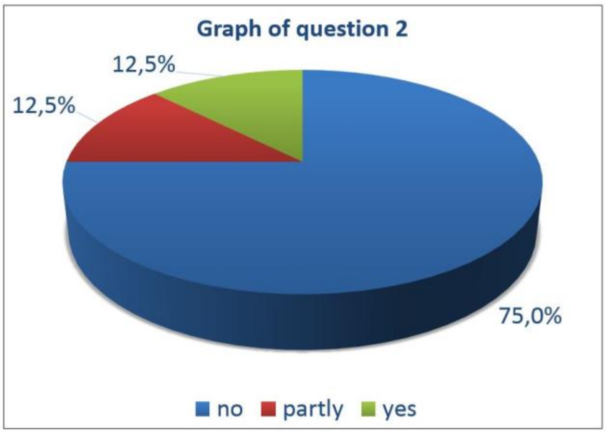

Figure 2. Graph of question two

Question three (3): Are you satisfied with collection of data in the maintenance information system?

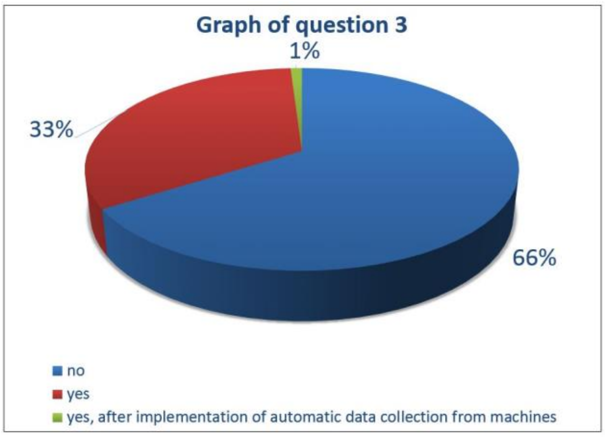

Figure 3. Graph of question three

Question four (4): What is your basis for planning maintenance intervals and their duration?

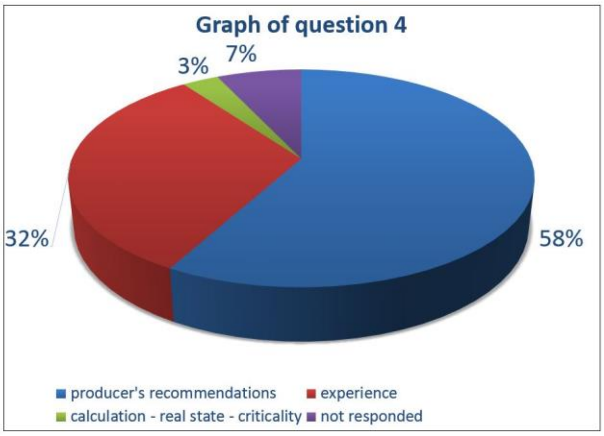

Figure 4. Graph of question four

3 RECOMMENDED STEPS FOR DESIGN

Simple copycatting of approaches and methods while implementing changes in a factory does not necessarily translate into the overall preservation of competitiveness of an industrial system of production. The factories are starting to realize the manufacturing processes are affected by customer requirements, technology, available machinery, pull system and the environment the factory operates in. However, by integrating pull systems in some of production processes, you will be able to reduce lead times, and perhaps associated costs [BubenIk 2015]. That is why they must reconfigure factory processes and start seeking support in digitalization and pull principles. Due to the above, it is necessary to determine a logical train of events a change should follow. The process should start with an audit and definition of responsibilities for technical condition of machinery and equipment. Authority for evaluating and motivating production and maintenance operators should be assigned and the results measured against economic and technical criteria. In order to launch a production system into an effective operation and to ensure its optimal long-term costs throughout its life cycle, it is necessary to design and plan maintenance activities (Figure 5) and to ensure they are backed up by necessary resources.

The goals of maintenance design and planning are the following:

- to develop a concept of maintenance and to supplement the systemic requirements with the maintenance requirements,
- to assess the proposed maintenance system effect as maintenance requirements and to optimize the maintenance concept,
- to define maintenance requirements and maintenance plan,
- to specify the necessary resources,
- to reconfigure maintenance system to reflect changing manufacturing conditions.

Introduction of a maintenance system is one of the best ways how to ensure effective implementation of maintenance activities in contemporary dynamic times. Under implementation of the said system, the factories are striving for best utilization of all physical, human and financial resources available to maintenance with the aim to maximize output effects. That means elimination of breakdowns occurring on machines and equipment, stabilization of performance and condition of machines and equipment, enhancing work safety, elimination of negative environmental impacts and other effects. The fifteen phases below present a framework of what an effective system for designing reliable and efficient maintenance processes in a factory should look like. These phases must also be the basis for the subsequent digitalization.

STEP 1: Defining production process and production system requirements.

STEP 2: Audit of maintenance processes and evaluation of operational reliability of machines and the cost-effectiveness of maintenance processes.

STEP 3: Breakdown analysis of machines and equipment as to the number of occurrences and the costs incurred.

STEP 4: Assigning machines and equipment into ´A´, ´B´, ´C´ categories.

STEP 5: Identification and classification of critical machine and equipment components and spare parts as being of ´A´, ´B´, ´C´, ´Z´ category.

STEP 6: Identification of causes and consequences of breakdowns and their criticality – performance of the FMECA (Failure mode, effects and criticality analysis).

STEP 7: Selection of maintenance method for each structural component: post failure maintenance, periodic maintenance, predictive maintenance, autonomous maintenance, etc.

STEP 8: Analysis of patterns in breakdown occurrence and their probability.

STEP 9: Evaluation of applicable methods of preventive maintenance and defining the length of maintenance interval – maintenance tact time.

STEP 10: Determining envisaged number of maintenance activities for service and maintenance operators.

STEP 11: Determining labour intensity for post failure maintenance, preventive, planned maintenance and calculating the available man hours of maintenance staff for the maintenance processes to be performed.

STEP 12: Analysis and allocation of maintenance costs and costs of reconfiguring maintenance systems.

STEP 13: Defining requirements for reporting the state of maintenance reconfiguration and suggested remedial measures.

STEP 14: Proposed system of maintenance organization and management based on goals and defined variations.

STEP 15: Monitoring reconfigurable maintenance system.

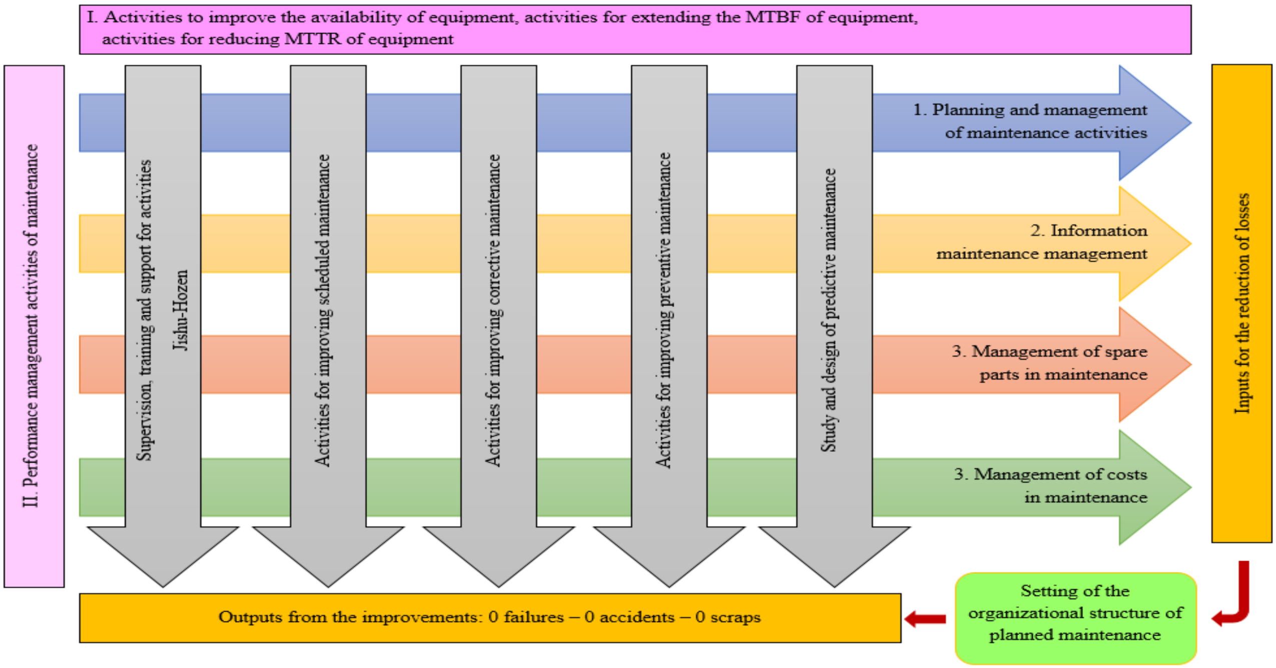

Figure 5. Concept of planned maintenance

3.1 Evaluation of the effectiveness of maintenance processes

The objective of activities aimed at production improvement is increased productivity by minimizing the ´inputs´ and maximizing the ´outputs´. The term ´output" is to be understood as activities aimed at improved quality, reduced costs, delivery deadlines in compliance with customer requirements, enhanced morale, better safety and health conditions and an overall improvement of work environment. The relationship between the ´inputs´ and the ´outputs" in manufacturing activities is illustrated in matrix of the Figure 4.

The inputs represent labour, material, machines and the outputs include production, quality, costs, supply, work health and safety and morale. A Three Zero program requirements are being set: Zero Accidents, Zero Defects and Zero Failure.

This program is a tool the factories use to focus on defect reduction through their prevention. It aims at motivating people to instill a desire in them to do one's job correctly right at the first attempt in order to prevent defects. It consists of 4 main quality axioms [Crosby 1979]:

- the quality definition reads as follows: Quality is compliance with requirements,
- the basic system of quality is: Prevention,
- standard for performance measurement is zero defects,
- standard of quality is: Cost of poor quality.

Subsequently, each factory defines its particular rules (principles, notions), to be adhered to by everyone in the factory. In general, the maintenance effectiveness is evaluated by application of the two methodology areas: Procedural methods, evaluating maintenance effectiveness in individual pieces of equipment (determining repair appropriateness, technical diagnostics introduction, etc.).

3.2 *Realization of program Three Zero*

The Three Zero program is achieved through implementation of planned maintenance concept aiming at ´0´ Faults - ´Zero failures´ [Crosby 1979]. It is based on a four-stage implementation program supported by standards with the following benefits (Figure 6):

PHASE 1: stabilization of time interval between occurrence of defects on devices (standardization autonomous maintenance).

PHASE 2: extension of lifetime (standardization preventive maintenance).

PHASE 3: periodic upgrade of deteriorated state of devices.

PHASE 4: prediction of lifetime.

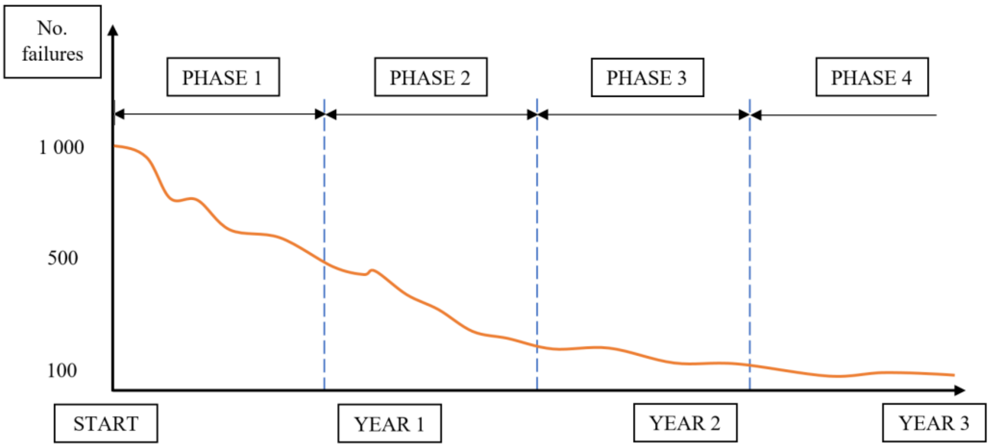

Figure 6. Benefits of program Three zero

4 THE BASIC SOLUTIONS FOR SMART MAINTENANCE

Maintenance is a phase in production engineering which have to be managed by several perspectives [Alexandru 2016]. In industrial practice, the basic effort is to reduce costs and increase profits. Often it happens by the changes, respectively manufacturing processes innovation. But we always talk about technological processes, which effort is to reduce their energy consumption, while taking into consideration the entire life cycle of technology systems, as well as selection of suitable maintenance strategy in order to minimize losses and waste [Pacaiova 2015]. Industrial production, which operates in a market economy, must deal with three key indicators: quality, productivity and efficiency. To achieve these targets, it is important to manage many tasks simultaneously. Those are in particular the following: the correct transition of products through the production system, collection and evaluation of data on production and maintenance, securing the resources of production and their control, monitoring of quality and time parameters. Technical diagnostics and the collection of product data needs to be adapted to the above.

4.1 *Troubleshooting*

The basic premise for proper implementation of proactive maintenance and decisionmaking is troubleshooting. It is an efficient reliability tool of great importance for the equipment operation and maintenance. One of the most frequently used troubleshooting methods for rotating equipment is vibrodiagnostics. The main component in these devices is a bearing which ensures the rotary motion and captures a dynamic load. High demands are currently put on modern machine tools; this affects not only their design and technological parameters, but also reliability and its diagnosability [Petkova 2017]. The most demanding is the operation of machine tools in unattended continuous operation.

With off-line diagnostics device, workers must carry it around the factory and troubleshoot the machines. The data thus collected are not the real time data. On the contrary, with the sensors and devices that are used for real time parameters monitoring, the data are transmitted in real time through a software, where they are processed further. Each of today's CNC machine (Computer numerical control machine) tools has a standard operating diagnostic.

Signals from measuring component are usually evaluated by PLCs (Programmable Logic Controller) and critical messages are displayed via the machine’s interface. Critical conditions induce a task programmed in the PLC (Programmable Logic Controller) to avert a crash or prevent damage. The number of quantities monitored in this way depend on the complexity of the machine. It is the order of units, maximum tens of the measured signal. Higher requirements for machine diagnostics lead to draft extensive diagnostic tools [Micieta 2014b]. The aim of troubleshooting is:

- to increase the service life and operational reliability of machinery and equipment,
- to reduce unplanned downtime due to faulty conditions of the machines and devices,
- to reduce the cost of repairs and maintenance.

4.2 *Data collection in factory*

Many factories at home and abroad still hold on to the paper form of data collection. This form was once a standard, but today it is no longer sufficient with the complexity of manufacturing and assembly growing, generating ever greater amounts of information. This phenomenon also increases the complexity and amount of maintenance work. The maintenance is increasingly employing a variety of Enterprise asset management (EAM) software, barcodes or QR codes (Quick Response codes), which facilitate and accelerate the work of servicemen, providing them with clear definition of the tasks to be performed. The modern trend is Enterprise asset management (EAM). However, if we are in confusion over the maintenance management, the introduction of this system will only further increase this confusion. The rule: bad input information = bad output information applies here. Such solutions are used in various industrial PCs (Personal Computers), smartphones, tablets, and other sensors [Fusko 2015].

The application of maintenance systems in factories has many advantages. One of the biggest is the elimination of paperwork and manual tracking activities, leading to the already mentioned greater productivity and cost reduction. The functionality of these systems is to collect and store information. The advantages of creating automated data collection systems, their transmission and processing are as follows:

- Correct data
- Clearly defined and legible
- Considerable savings of time and cost
- Rapid ROI (Return on Investment)
- Elimination of errors caused by the human factor
- Clarity of records

4.3 *The use of codes in practice*

The most important practical parameters of barcodes are density and contrast of the code. The amount of encoded data per unit length determines the density and type of the code. Linear codes are used for encoding fewer characters; a larger volume of information has been successfully encoded in a two-dimensional code.

Code usage will lead to decentralization of production and centralization of maintenance with an autonomous decentralized control based on the state of the machinery. This will create reciprocal links between machines, production processes and production environment and their requirements in real time. This will enable the machines to identify what happened when there is a failure, why there is no production, what has been done to it and what is to be done. Depending on the decision is taken by the worker moves to fix that. [Fusko 2015] The entire collection of information via codes must work on the PDCA (plan-do-check-act) (Figure 8).

These relations will also include suppliers (warehouse spare parts), partners and even internal customers. This will require a new decision-making algorithm and applications interconnecting the information required from large data stores to ensure that everything is working soundly and is synchronized throughout the value chain, i. e. all elements of the manufacturing process. The final desired effect should be a lower unit cost of production, greater flexibility of service processes. Figure 7 illustrates the use of a QR code on a steel rod. This label with QR code (Quick Response code) and material characteristics helps warehouse workers to quickly load goods into storage devices or shelves.

Figure 7. QR code in practice

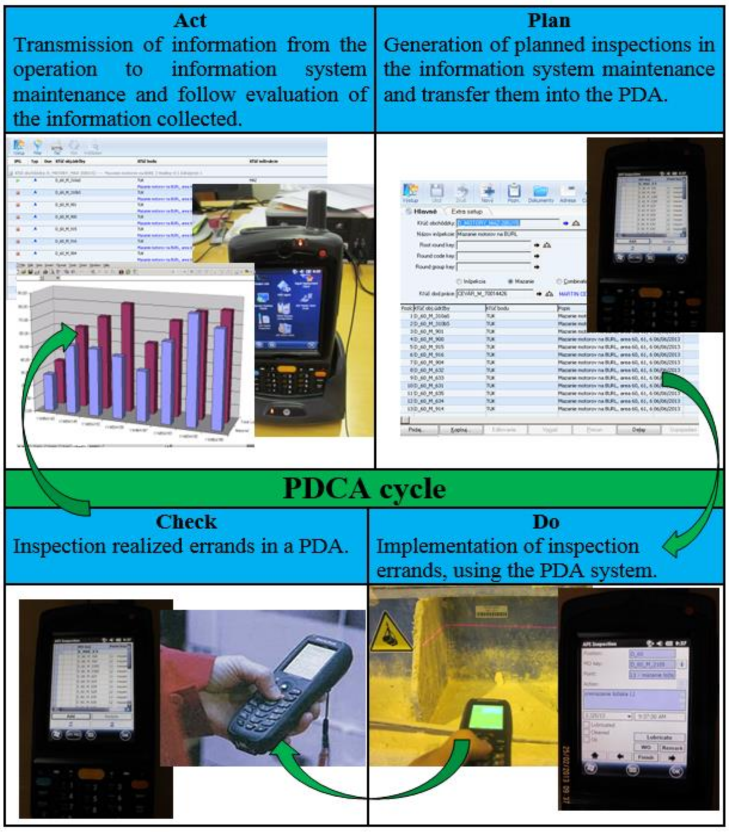

Figure 8. Use barcode

RFID (Radio Frequency IDentification) application is very widespread, from traceability of chocolate moulds, through traceability in meat processing, vehicle identification, pallet identification, material identification, assembly pallet tracking, tool identification, and so on. It is an easy, effective and flexible production tracking. RFID systems (Radio Frequecy Identification systems) help automate and error-proof tool tracking processes to ensure the correct tool is being used and track the cycle time for preventive maintenance.

4.4 Safety and utility of codes in practice

The question may be: what is currently really safety? Companies implement different codes e. g. barcodes, QR codes (Quick Response codes), RFID (Radio Frequency IDentification) and other, to simplify their work and lacks elimination. At digital solutions are undoubtedly a greater risk of security. At present, many factories using effective tools to prevent of digital data loss. Discussion of some of the codes used in a practise:

Barcodes – very extended. Advantage: faster and easier work. Disadvantage: the software cannot count on a small part of the barcode hidden - cannot be used in dirty and aggressive environments.

QR codes (Quick Response codes) - opportunity of encoding a large amount of information, very useful everywhere. Advantage: the software can count a small covered part of QR code (Quick Response code). Disadvantage: cannot be used in dirty and aggressive environments.

RFID tag (Radio Frequency Identification tag) - automatic product identification, very useful in industrial environment or in some kind of business. Aplication: tracking of number of pallets, tracking of machines, devices, identification of persons, measurement and monitoring of temperature, pressure, lighting, etc. Advantage: writing and changing information, use in aggressive environments (varnishing, burning). Disadvantage: cost of implementation of this solution.

Marker - a special picture to which the app is "learned". Solution for augmented reality. Nowadays is very popular too in industrial factories, where is used augmented reality. Aplication: description of the fault and this will be addition with a marker, for clarity of the problem, after the marker is scanning, service man will see what to do. Disadvantage: the larger image we want to encode, the more we need a marker.

5 NEXT RESEARCH AND FUTURE DEVELOPMENT

The globalized economy is strongly influenced not only by economic cycles but also a rapid change in customer behaviour, which result in turbulences. Business community should continually find new ways to respond to these incentives. One of the effective solutions is the use of reconfigurable manufacturing systems (RMS) [Gregor 2015].

Reconfigurable manufacturing systems (RMS) are designed for rapid change in it is structure, as well as it is hardware and software components. The goal of Reconfigurable manufacturing systems (RMS) is making quickly changes in production systems, e. g. proposed as a solution to unpredictable situation in factories or fluctuations in market demand and market turbulence.

Industry 4.0 combines the efforts of scientists and industry into an integrated system. Becoming a Digital Factory (DF) is increasingly gainig significance as a factor of factory survival, but the way forward is not always clear and simple. Figure 9 describes requirements and assumptions related to steps and phases of transformation.

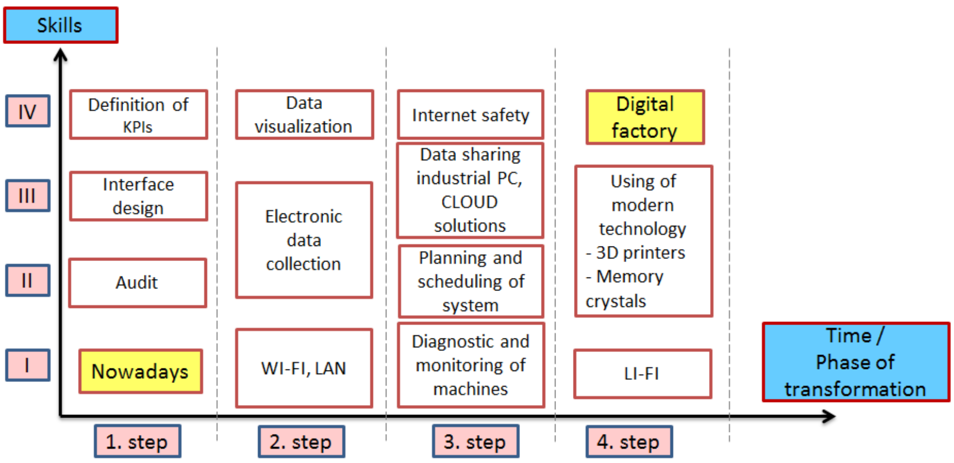

Figure 9. Model of transformation of technical service for digital factory

Despite the fact that maintenance management can be highly technical in nature, maintenance teams are often the last in an organization to get new information technology (IT) systems. The maintenance department's typical workday includes highly technical and specialized tasks related to a broad range of advanced technologies. Until recently, though, information technology has not been considered relevant for maintenance staff. But the truth is the information technology is just as important as any other tool in the maintenance team's toolbox. The same information technology systems that make other departments like finance and marketing more effective are also important for maintenance, repair, and operations (MRO) professionals. Even today, as technology is rapidly integrated elsewhere in organizations, many maintenance departments are just now implementing PCs (Personal Computers) and related technology, like Enterprise Asset Management (EAM) software [Pacaiova 2013]. With the help of EAM software (Figure 10), critical data can be captured for making good decisions to help your organization save time and money. This software is as a best practice ´champion" who understands these trends, you can personally become the leader who keeps your organization at the top of its game [Bubenik 2015].

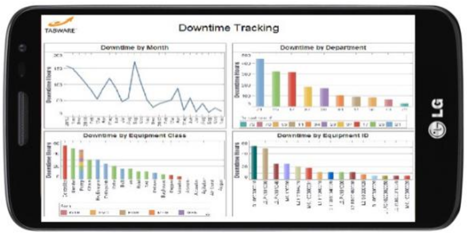

Figure 10. Enterprise Asset Management (EAM) software on smartphone

5.1 Recommended practices of the digitization of maintenance management

Companies are alarmed by the buzzword ´digitization´ and do not know specifically what to do. They are hearing about the threat of new business models, reading about the enormous sums paid for startups which have not yet made a single euro of profit and that Industry 4.0 will distort the processes that are used now. And here is the problem: All of this will be true - the massive attack on the status quo has already started!

Therefore, we invented a sequence of steps based on the model. These steps and recommendations are general and each factory must adapt these steps to their conditions. If the factories want to be competitive, they must implement digitization and new things and approaches.

STEP 1: Audit of maintenance in terms of complexity and preparedness for Industry 4.0 and Maintenance 4.0.

STEP 2: Verification of the data maintenance management - Proposal of digitization project.

STEP 3: The segmentation of production processes - selection operation on digitization maintenance.

STEP 4: Quantification of items of configuration of maintenance system for digitization.

STEP 5: Setting the criteria and knowledge of configuration items for maintenance - the decision making model - digital twin (digital factory).

STEP 6: The choice of means of technical diagnostics, PLM solutions, modules for data acquisition and monitoring machines.

STEP 7: Implementation of data collection - the proposed structure of data management, cloud computing, technical, PDA, tablet, mobile applications, software and solutions.

STEP 8: The proposal of organizational changes and maintenance management on the principle of digitization.

STEP 9: Implementation of digitization maintenance in the selected of operation, verification and presentation of economic benefits.

STEP 10: Launch digitization of system of maintenance at the factory level.

5.2 Digitization and Crystal memory

Digitalization opens a door to wonderful new opportunities. That, however, does not mean the old ones will disappear. Classic products will continue to be produced, but in the future, their combination with software solutions will become an option that will furnish them with an entirely new dimension. They will accelerate the way we cooperate, develop business and communicate.

Each minute, the Apple's App Store witnesses downloading of 48,000 applications. Every hour, 5 million electronic devices connect to the internet. Each day, the same number of data is created as was the case from the cradle times of our civilization up to 2003. That is an enormous amount of data the conventional storage systems will not be able to handle. One way how to imagine the future is through memory crystals. All of us have seen those sci-fi movies where a magnificent stranger inserts a pointed crystal into a super computer and everything is stored and the world is saved. It seems, though, this sci-fi has become reality nowadays. [Peri 2013]

According to scientists from Great Britain and the Netherlands, who introduced the technology for the first time (the team leader Jingyu Zhang), data encoded in glass, i.e. the so called memory crystals, could in theory remain unchanged over millions of years. The data storing technology uses a laser to change optical properties of fused silica in nanometer range. According to scientists involved in the research, the storing potential of this technology is a breath-taking 360 terabytes of data, which accounts for approximately 75,000 DVD of standard disc size and it can withstand a temperature of up to 1,000 ºC. These two statements then lead to a conclusion that when handled properly, the crystals could last millions of years, trouble free. [Peri 2013]

6 CONCLUSIONS

An increase in variability and individuality of products lead factories to decrease their production lots and make changes more often. Every factory has to respond to changed circumstances flexibly. [Bardy 2014] Current practical requirements show that it is necessary to design a strategy of proactive maintenance processes and technical service on the principle of implementation and integration of TPM (Total Productive Maintenance), RCM (Reliability Centred Maintenance), RBM (Risk Based Maintenance), VDM (Value Driven Maintenance) and digitization steps. This implementation ensures optimal operational reliability at optimum cost of the whole technical service. As has been shown, it is necessary to adapt the direction of the current maintenance, because Smart Things surround us already to a large extent. The paper outlines the view of how maintenance could be integrated into this new change in industrial factories. On the basis of these premises, it is necessary to solve and develop technical services in the factories. If high-tech is not introduced in production, logistics and technical services and these areas will lag behind, long-term sustainability of such systems will not be possible. It can be reasonably assumed that the development will continue, bringing about a Smart World in the years to come. The practical ramifications of such development are already witnessed at present, widely used by some elements. Maintenance or technical service certainly will not disappear but will evolve into a sophisticated system.

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