TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 66, Issue Special I, September, 2023

THE IMPLICATIONS IMPOSED BY PRESCRIPTIVE MAINTENANCE IMPLEMENTATION INTO THE INDUSTRY 4.0 - A CURRENT STATE ANALYSIS

Ana-Diana POP-SUĂRĂŞAN, Nicolae Stelian UNGUREANU

Abstract: *In the context of an information technology era, digitalization and a fulminant technological evolution, the prescriptive maintenance occupies a crucial place for increased automation and continuous improvement processes. The concepts and technologies of Industry 4.0 can be applied to various industrial models, starting from the production line and continuing to the decision-making act.*
The automation, design and operationalization of maintenance plans are becoming more and more effective due to technologies based on the processing of the Artificial Intelligence's machine learning algorithms. Concretely, this paper aims to address a method in which an innovative maintenance strategy, such as the prescriptive one, can influence the organizational development.

The predictability, the visibility and the efficiency of the prescriptive analytics and the use of technologies such as the Internet of Things and Big Data provide an improved interconnectivity between systems. Thus, the research proposes to achieve a strategy to determine the manner and application degree in which the prescriptive maintenance will be applied depending on the organizational technical characteristics. This paper presents an analysis of the specialized literature in the field of maintenance, which allows the identification of further research directions.
Key words: *Prescriptive maintenance, Industry 4.0, Management, Change mechanism.*

1. INTRODUCTION

The increase in reliability, the increase in component prices and the improvement of manufacturing technologies related to Industry 4.0 have led to the integration of modern systems in order to obtain effective prescriptive maintenance plans. The trend of the modern era, the integration of computerized subsystems in simple or complex systems, is part of the fourth industrial revolution that we are currently experiencing. The theories developed today can be applied by combining technologies of any kind with digital ones, creating systems capable of intelligent performance for the fulfillment of complex tasks. By applying machine learning algorithms, manufacturers can detect faults immediately, rather than at later stages when repair work can become expensive [2].

The development of IT-smart companies provides an incredible opportunity for the manufacturing industry to enter the fourth industrial revolution. Analysis of the large amounts of data captured by the company's sensors provides real-time observation of production assets and can provide tools for performing prescriptive maintenance and minimizing downtime for equipment and production lines. Replacing manual inspection patterns with Artificial Intelligence-based visual information reduces manufacturing defects [7], lowers costs and increases efficiency.

The evaluation process of the development of a system is based on verification and validation processes and includes the evaluation of the requirements, the description of the test specifications and the control reports. With minimal investment, quality control personnel can set up a cloud-connected smart terminal to monitor production processes from almost anywhere, regardless of the nature of the job. In the context of technological evolution, it can be stated that the process of applying maintenance to equipment is much more efficient than in the past. This process improvement refers both to the duration of use with few operations and short maintenance time, as well as to the total duration of use [12].

2. INTEGRATIVE ANALYSIS AND SUBSTANTIATION

Systems evolve over time, from natural ones, specific to primitive society, to systems that began to dominate life with the emergence of industrial society. Technological and scientific research activity has led to the realization of complex physical and technical systems [8]. The functioning and the behavior of the economic system alike are influenced to a significant extent by the way in which the systems are structured, by the dynamics of the interactions between the component subsystems, as well as by the fundamental concepts of the systems theory.

At the same time, as presented in the work [14], the situation of digitization and the effective integration of methods and techniques based on computerized assistance is constantly rising, in different fields such as: urbanism, administration, management or development. Of course, all these programs are designed and implemented with a specific purpose. The maintenance of each device involved finds its importance in their subsequent good functioning.

2.1 Specific prescriptive maintenance technologies

Adopting any measures to reduce the number of defects involves additional costs in the development and production phases. Choosing a system involves analyzing its functional and technical performance. Because of the impressive amount of general knowledge, there is no easy way to put it into an intelligent program such as a specialized one like an expert system. The functional core of the system is usually considered to be the body of knowledge structured to enable decision-making act. This information may take the form of facts or rules, which in the case of an expert system, are not always true or false. Sometimes, there may be a degree of uncertainty about the validity or correctness of the resulting aspects [3]. Many times there is the possibility that a certain expert system gives hints in the form of directives on process dysfunctions or technical failures.

The authors of the paper [11] claim that predictive maintenance is often based on the continuous monitoring of equipment behavior, generally provided by sensors or even the component. Additional data from the management software, including what materials are used and what processes are performed on the equipment, can be used to enrich the data flows, and ontologies can be used to bridge the gap between these different domains, while facilitating understanding the results obtained through the analytical methods applied to the data.

2.2 Industrial system development

During the lifetime of the equipment, the type of maintenance may vary depending on its nature. It can be just a routine maintenance task (due to a malfunction discovered by a user) or it can be a significant event based on the size or nature of the maintenance. In the case of the procedure in which maintenance is carried out in organizations, a general sequential pattern can be observed [5]. The first phase consists of analyzing the program to understand its functionality. The second stage consists in the generation of a certain proposal to achieve the implementation of the maintenance objective. The third step consists in accounting for all changes as a consequence of program changes. The fourth phase consists of testing the modified program to ensure that the modified program has at least the same level of reliability as before. Each of these four stages and their associated software quality attributes are critical to the maintenance process. All these factors must be interconnected to form a coherent maintenance plan.

The specific techniques consider the continuous monitoring of processes based on the state of the equipment. The evaluation of each step within an automaton can, in fact, constitute a state related to the monitored equipment. Such an evaluation is carried out by means of the sensors and the multiple data characteristic of the processes evaluated. The state of each piece of equipment can negatively influence the results of the monitoring, thus resulting in values that are inconsistent with reality.

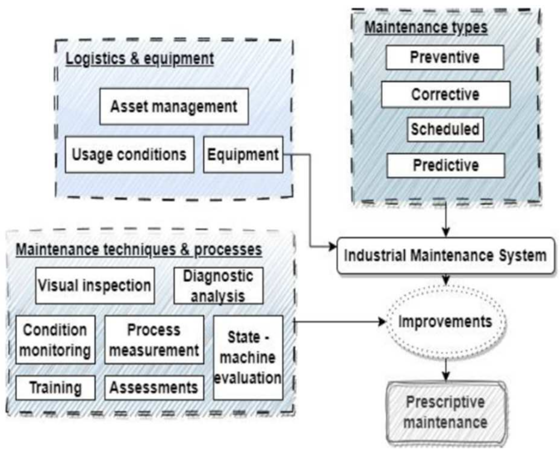


Fig. 1. The main specific components of an industrial maintenance system.

Of course, as illustrated in Figure 1, the way of applying the types of maintenance depends on one system to another. As a rule, in the case of industrial systems, various processes are encountered, such as: visual inspection, system analysis, condition monitoring and process measurement. In the application of current maintenance principles, for example, the focus is on the event, so the main objectives are visibility and the analysis and collection of information held up to a trigger point. Situations and goals change in the case of corrective maintenance, so it is desired to identify the reason why an event occurred. In this case, the focus is on transparency and traceability, on cause-effect analysis and on collecting as many technical specifications of the entire process as possible.

3. TRENDS IN MAINTENANCE SYSTEMS

Following prescriptive maintenance engineering, it aims to reduce the probability of defects, identify critical points and correct design and manufacturing deficiencies, develop the necessary measures to establish the best practices for operation, maintenance and repair [15]. This allows operators superior planning of maintenance parameters (such as place, specific time) in order to reduce turnaround times and ensure availability of the necessary spare parts stock.

3.1 Current implementation of the maintenance plans

In contemporary society, industrialization occupies a leading place in the processes of both economic and community changes. Thus, as the development of the factors related to technological processes is in a perpetual ascent, the need for the maintenance of all equipment, computer programs, respectively various services is increasingly accentuated [13]. Tasks such as cleaning, lubrication, adjusting parts, reporting observations regarding the condition of the equipment used are useful in preventing some of the causes that can lead to system failure, but they cannot completely stop the multitude of failure possibilities.

More detailed information about the equipment can become important to ease the operator's maintenance burden, given that it can identify subsequent malfunctions. In the paper [10], the author emphasizes that the main objective of all maintenance systems is to keep the equipment, machines or machinery in working condition. In the same study, it is mentioned that there are multiple norms on the basis of which a certain classification of maintenance works is carried out, such as: those depending on the resources used, depending on the existence of certain repair and maintenance costs, or taking into account actions to prevent of possible wear and tear or damages to the systems. Reactive unplanned maintenance also known as corrective maintenance takes into account the unexpected, emergency cases, which can lead to the highest costs. The planned maintenance strategy is most often used as a strategic maintainability method. The basis of planned maintenance consists of clear, highly accurate information from the systems to be maintained.

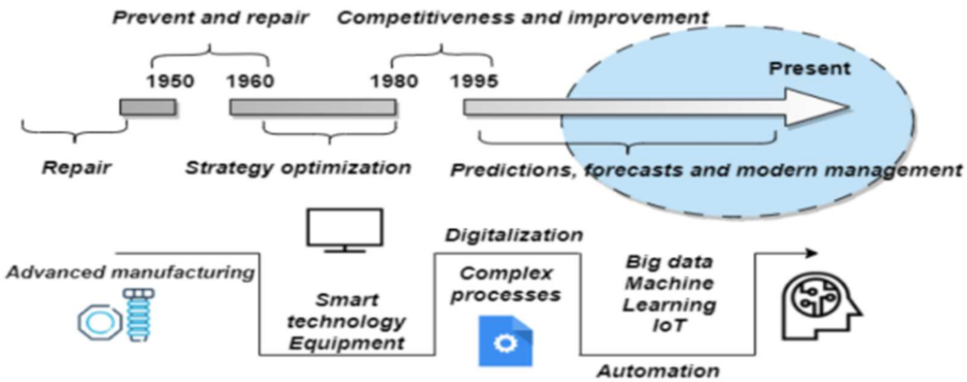
Using preventive maintenance, the efficiency of equipment components is evaluated at regular time intervals, which can extend their life. This type of strategy is designed to overcome the disadvantages of corrective maintenance by reducing the probability of failure and avoiding sudden wear and tear. Predictive maintenance involves the use of diagnostic tools used to anticipate possible failures and to prevent their occurrence. One of the most common types of maintenance is preventive maintenance, it prevents possible breakdowns, improves the operation of a system and extends the lifetime (optimal functioning) of the various system components of which they are a part [1]. Concretely, the use of this type of maintenance helps to reduce downtime, reduce the number of necessary repairs or detect weak points that can affect the proper functioning of the system.

The maintenance strategy used depends on the problem detected, but the most important thing is how the method itself is planned. Although all maintenance strategies can contribute to extending the life of equipment, except for corrective maintenance, the most relevant maintenance strategy is preventive maintenance at this time. Preventive maintenance provides adequate schedule for the maintenance of facilities, systems and helps in equipment management and cost planning [6].

3.2 Automatic comprehension

Predictive maintenance uses Machine Learning techniques to learn from historical data and use real-time data to analyze failure patterns. Because conservative procedures lead to wasted resources, predictive maintenance using Machine Learning looks for optimal use of resources and predicts failures before they occur. In the case of knowledge-based systems methodologies, existing ontologies model these issues independently, and a holistic view that considers the temporal requirements of predictive maintenance is not yet available. Figure 2 illustrates the temporal evolution of the main maintenance strategies used in industrial systems. It is possible to observe both technology differences and developments related to applied methodologies. Thus, it is noted that the trend is towards digitization, using advanced computational technologies, such as Big Data, Internet of Things and Artificial Intelligence [4].

Fig. 2. Temporal evolution of the maintenance strategies and the main technologies used.



Maintenance systems have undergone significant changes in recent years, thanks to technological advancements, and the need for more efficient and effective methods of maintaining equipment and facilities. One of the most significant trends in maintenance systems is the shift from reactive and preventive maintenance to prescriptive maintenance. With prescriptive maintenance, maintenance teams use sensors, data analytics, and machine learning to predict when equipment is likely to fail and take corrective measures before it happens. This approach reduces downtime, extends equipment life, and saves costs. Digitalization allows maintenance teams to collect and analyze data more effectively. With digital tools, maintenance teams can collect data from a wide range of sources, including sensors, Internet of Things devices, and equipment logs. This data can then be analyzed using machine learning algorithms to identify patterns and predict potential failures.

4. USE CASES SPECIFICATION

When applying a maintenance plan, the designated manager has multiple applicable strategies at his disposal. The state-of-the-art policy [9] uses a maintenance policy that includes use-until-failure, planned maintenance and sometimes occasional maintenance (depending on the situation) is used. The state-of-the-art policy uses a combination of run-to-failure maintenance, time-based maintenance, design-based, condition-based maintenance, and opportunity maintenance. Testing and assessments are important because their results determine if specific equipment or devices are functioning properly and if they can fulfill the tasks they were designed for.

4.1 Defined pre-conditions and post-conditions

The need to shorten the time applied for maintenance operations motivated the development of methods whose main purpose is the rapid evaluation of the system's condition, but also the elimination of subassemblies with a major failure risk. Decisive in the case of real time is receiving the answer quickly enough to be able to influence the development of the process. Testing to verify the tolerances of the design to extreme environmental conditions, fatigue or other effects that can limit the life of the equipment is important. In this way, the systems can be analyzed individually in detail. A rigorous control applied overall production phases, as well as the identification of non-conformities in the specific environment can lead to the improvement of the maintenance plans already applied.

Preventive maintenance supports replacement or repair at a predetermined time, independent of system status. The timing of maintenance activity in a preventive maintenance program is calculated to minimize total costs. This strategy is viable as long as the propensities for future failures are known. Most failures will be anticipated, prevented, but some will still occur due to uncertainty about the distribution of ancillary failures of the systems concerned.

4.2 Alternative development of application scenarios

Currently, computer systems represent the main functional elements of the industry, regardless of the category they belong to. They constitute basic elements for the planning, verification, monitoring and control of the processes that are carried out in various fields. Thus, constant monitoring of both the activities undertaken and the systems themselves is essential. From this point of view, reference is made to all the changes in the IT systems that can lead to their effective adaptation, to a specific organizational climate or to an integration that contributes to possible corrections of some obstacles in the proper functioning of the processes.

Figure 3 graphically illustrates the flow followed, necessary for obtaining a viable maintenance prescriptive system. Among the conditions are mentioned: performing regular inspections, using the right resources and correct documentation of the systems and components used. Among the attributes that must be taken into account when applying a certain type of maintenance, the following are listed: performance, response time, as well as the possibility of adaptation to a certain context.

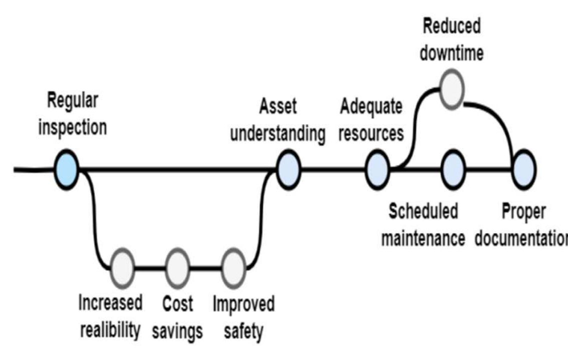


Fig. 3. Conditions and consequences of the prescriptive maintenance system.

Predictive analytics is a category of data analysis that aims to return predictions about possible future events based on already existing data and analysis techniques such as statistical modeling and machine learning. With the help of sophisticated specialized analytics tools and models, any organization has the ability to use the collected data to accurately forecast future trends and machine behaviors.

4.3 Component assessment and monitoring

Taking into account all the processes that intervene on the equipment used, the importance of updating each individual component emerges. Thus, the component that is an integrative part of a piece of equipment will positively influence its operation through the state of accuracy. Of course, services are the result of all the interactions between components, processes and equipment, as illustrated in Figure 4, the intervention of an error or a manufacturing or processing defect influences the entire complex of interconnections, thus reaching inconsistent data. Not only do they not bring any kind of value to organizations, they can refer to a completely different usage paradigm. System maintenance must be applied starting from the smallest sub-assembly, from the component itself. Afterwards, maintenance operations must be applied to all resort equipment. The correct application of specific operations results in minimizing errors and reducing the number of malfunctions.

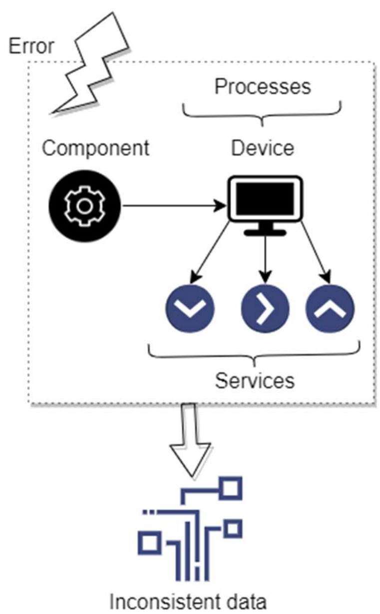


Fig. 4. The influence of error or dysfunction occurrence on the expected results.

The occurrence of an error or defect can have a strong influence on the final results given by a subassembly or component, it no longer being able to give the expected results, ultimately affecting the performance of the entire system or equipment. For this reason, a constant evaluation and monitoring process is important in order to avoid situations of this kind, as well as to minimize the negative effects it could have on the system or the equipment of which it is a part.

5. CONCLUSIONS

Prescriptive maintenance is a maintenance approach that combines predictive maintenance and machine learning algorithms to provide recommendations on the best course of action to prevent equipment failure. It goes beyond predicting when a failure will occur, and instead offers specific actions that should be taken to prevent the failure from happening. Prescriptive maintenance is still a relatively new concept, but it is already being applied in several industries today. As technology continues to advance, prescriptive maintenance is likely to become more prevalent across a range of industries in the future. Human expertise can quickly depreciate, so any significant period of non-use of knowledge can seriously affect the performance of the system it manages. The presented article represents the initiation of academic approaches in the context of doctoral studies.

The evaluation of the quality of a system is a complex process that includes the evaluation of the quality of development and the evaluation of the entire manufacturing process and related activities. During the operation of a particular piece of equipment, a series of mechanisms degrade its physical integrity and finally, after a given time of processing and operation, the equipment breaks down. In order to understand the defects, it is important to know the interconnection mechanisms, how the utility was used and its interaction with other systems. The critical examination of the data has a fundamental role and it can be stated that, in fact, the efficiency of the developed system is determined by the manner and the degree of depth of this analysis. Thus, the more systematic and intensive the investigation of the attributes that characterize the data and the methods used, the more conclusive the results will be from the point of view of decision-making efficiency.

Although machine learning has been transformative in some fields, machine learning programs often fail to deliver the expected results. The reasons for this are many: lack of adequate data, induced biases, privacy issues, inappropriately chosen tasks and algorithms, wrong tools, lack of resources, and the emergence of potential assessment problems. The increase in the complexity of economic activities, the increase in demands for the most complete utilization of existing resources, the dynamics of decision-making have gradually led to a considerable increase in the need to implement a suitable maintenance system. As possible further developments, it is worth noting the calculation of the availability of the systems, the standardization of the way of checking the functionalities, but also the development of easy accessibility to the data circulated in the system through the integration of an enterprise resource planning type system.

In case of defect identification and advanced data processing, it is recommended to integrate an expert system that can rationalize the entire system, thus offering recommendations or justifications for the decisions taken. Of course, the involvement in digitalization in Industry 4.0 is currently noteworthy. This induces the meticulous research of the field, which for now must be discovered in its true value. Although there is a considerable series of research and works in the area of study related to prescriptive maintenance, a broad analysis of the field prompts new discoveries and remarks will be extremely useful in the development of effective maintenance systems.

6. REFERENCES

[1] Adamides, E., Karacapilidis, N., *Information technology for supporting the development and maintenance of open innovation capabilities*, Journal of Innovation & Knowledge 5.1, pp. 29-38, ISSN 2444-569X, 2020.

[2] Ghobakhloo, M., *Industry 4.0, digitization, and opportunities for sustainability*, Journal of Cleaner Production, vol. 252, 2020.

[3] Griffiths, F., Ooi, M., *The fourth industrial revolution-Industry 4.0 and IoT Trends in Future I&M*, IEEE Instrumentation & Measurement Magazine, vol. 21.6, pp. 29-43, 2018.

[4] Jay, L., Hossein, D., Shanhu, Y., Behrad, B., *Towards an intelligent maintenance optimization system*, Procedia CIRP 38, pp. 3-7, 2015.

[5] Kobbacy, K. A. H., Nathan, C., Harper, A. M., *Towards an intelligent maintenance optimization system*, Journal of the Operational Research Society, vol. 46.7, pp. 831-853, ISSN 1476-9360, 1995.

[6] Mattioli, J., Paolo, P., Robic, P. O., *Improve total production maintenance with artificial intelligence*, 2020 Third International Conference on Artificial Intelligence for Industries (AI4I), IEEE, 2020.

[7] Morrar, R., Husam, A., Saeed, M., *The fourth industrial revolution (Industry 4.0): A social innovation perspective*, Technology Innovation Management Review, vol. 7.11, pp. 12-20, 2017.

[8] Nadakatti, M., Ramachandra, A., Santosh Kumar, A. N., *Artificial Intelligence-based condition monitoring for plant maintenance*, Assembly Automation, vol. 28, pp. 143-150, 2008.

[9] Onawoga, D. T., Akinyemi, O. O., *Development of Equipment Maintenance Strategy for Critical Equipment*, The Pacific Journal of Science and Technology, vol. 11(1), pp. 328-342, 2010.

[10] Pintelon, L., Parodi-Herz, A., *Maintenance: an evolutionary perspective*, Complex system maintenance handbook, Springer, pp. 21 - 48, 2008.

[11] Poor, P., Zenisek, D., Basl, J., *Historical Overview of Maintenance Management Strategies: Development from Breakdown Maintenance to Predictive Maintenance in Accordance with Four Industrial Revolutions*, Industrial Engineering and Operation Management, pp. 495 – 504, 2019.

[12] Ungureanu, N., Ungureanu, M., Cotețiu, A., Bari, B., Grozav, S., *Principles of the maintenance management,* Scientific Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology, vol. 24, 2010.

[13] Ungureanu, N., Ungureanu, M., *System of Predictive Maintenance*, Scientific Bulletin

Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology, 2015.
[14] Ungureanu, T., *The potential of City Information Modeling (CIM) in Understanding and Learning from the Impact of Urban Regulations on Residential Areas in Romania*, The 15th International Scientific Conference eLearning and Software for Education Bucharest, pp. 422 – 428, 10.12753/2066-026X-19-056, Bucharest, April, 2019.
[15] Xu, L., Eric, X., Ling, L., *Industry 4.0: state of the art and future trends*, International Journal of Production Research, vol. 56, pp. 1-22, 2018.

IMPLICAȚIILE IMPUSE DE APLICAREA MENTENANȚEI PRESCRIPTIVE ÎN INDUSTRIA 4.0 O ANALIZĂ A STADIULUI ACTUAL

În contextul erei informatice, a digitalizării şi a evoluției tehnologice fulminante, mentenanța prescriptivă ocupă un loc crucial în cadrul proceselor de automatizare sporită şi a celor de îmbunătățire continuă. Conceptele şi tehnologiile corespunzătoare Industriei 4.0 pot fi aplicate în varii modele industriale, începând de la linia de producție şi continuând până la actul decizional. Automatizarea, proiectarea şi operaționalizarea planurilor de mentenanță devin din ce în ce mai eficiente datorită tehnologiilor bazate pe prelucrarea algoritmilor de învățare automată specifici Inteligenței Artificiale. Concret, acestă lucrare are scopul de a trata modul în care aplicarea unei strategii de mentenanță cu caracter de noutate precum cea prescriptivă influențează dezvoltarea organizațională.

Predictibilitatea, vizibilitatea şi eficiența analizei prescriptive şi a tehnologiilor precum Internet of Things şi Big Data oferă o interconectivitate sporită a sistemelor. Astfel, utilizând această cercetare, se va obține o strategie prin care să se determine modul şi gradul de aplicare a mentenanței prescriptive în funcție de specificul sistemelor tehnice. Lucrarea prezintă o analiză a literaturii de specialitate în domeniul mentenanței, care permite identificarea ulterioară a unor direcții de cercetare viitoare.

Ana-Diana POP-SUĂRĂȘAN, PhD student, Eng., Technical University of Cluj-Napoca, Faculty of Engineering, Department of Engineering and Management, ana.pop@campus.utcluj.ro, 62A Dr. Victor Babeș Street, Baia Mare, Romania, 430083.
Nicolae Stelian UNGUREANU, PhD, Eng, Professor, Dr. H.C., Technical University of Cluj-Napoca, Faculty of Engineering, Department of Engineering and Management, nicolae.ungureanu@imtech.utcluj.ro, 62A Dr. Victor Babeș Street, Baia Mare, Romania, 430083.