TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special III, Jully, 2024

AN ANALYSIS OF INNOVATION OF THE DIGITALIZATION PROCESS FOR THE DEVELOPMENT OF PRESCRIPTIVE MAINTENANCE PLANS

Ana-Diana POP-SUARASAN, Nicolae Stelian UNGUREANU

Abstract: *A modern management of the maintenance activity involves a long-term concern for increasing efficiency, to achieve predetermined objectives. Quick technological change has emphasized the development of innovative processes necessary to implement prescriptive maintenance plans. The innovation of the digitalization process requires the improvement of facilities, skills and technologies used for the proper functioning of the technique in use. Undoubtedly, at process innovation level, both the multiple technical market trends and the appropriate project implementation framework will be taken into account. In this regard, digitalization increases both the automation processes and the interconnectivity of production elements. Prescriptive maintenance plans can also be defined by software engineering methods, with the aim of ensuring the optimal system operation, contributing to ensuring the availability of the system, optimizing the resources consumption and preventing the system's wear. This study presents the prototyping of the process-based innovation model within the context of prescriptive maintenance. To highlight the digitalization elements, specific software engineering concepts were used, as well as the inclusion of advanced computational technologies.*

Key words: *o process innovation, prescriptive maintenance, digitalization, software engineering.*

1. CONTEXT AND MOTIVATION

The multitude of innovation elements includes all digitalization and development processes from a technical point of view. The engineering fields are monitored in a special way, considering the fact that with Industry 4.0, computational changes are on the rise. The optimization of the technologies used consists in the processes of adaptation to new technologies such as Artificial Intelligence or mass automation [7]. The introduction of prescriptive maintenance within the innovation procedures represents a benefit both at the level of maintainability plans and at extending the optimal life span of the equipment used. Industry 4.0 is important due to the fact that it brings new technologies and methodologies into production, which improves efficiency, flexibility and product quality [14]. It is based on the use of digitization, automation, interconnectivity and Artificial Intelligence in production. In the context of the current requirements of the field of production, manufacturing and operationalization can be found a pressing need for updating, modernization that would favour the activity of the specialized engineer in a beneficial way [1].

Over this area of interest hovers the idea of innovation in technological development through the prism of the novelty character introduced. New technologies address the challenges posed by: the growing share of unstructured and structured data generated by highly prolific and widespread data sources, and the growing gap between the available amount of relevant data and the ability to process it in time for decision support.

Prescriptive maintenance uses Artificial Intelligence, big databases, machine learning methods to generate expert recommendations that reduce operational technical risks [9]. Around the context of prescriptive maintenance, an antithesis between state-of-the-art technology and consensual roots can be considered to have been created over time. Although of high importance, predictive analytics is only one component of the full potential of applied machine learning as a technology. Prescriptive maintenance goes beyond the simple identification of defects and impediments, also providing viable options for optimizing processes [6].

Thus, process innovation occurs when the facilities, skills and technologies used for the production and execution of software services are improved and innovated. The new informational civilization is based on the availability and accessibility of information [4]. In a production situation, for example, the engineers can encounter multitudes of workstations interconnected by complex networks, which, in turn, depend on the correctness and speed of maintenance operations performed over time [2].

The whole maintainability process applied to the domain must implicitly be periodically updated, either by rigorously applying all the rules, both preventive and corrective, or by introducing the prescriptive aspects, of new technology, which cover the whole domain to be analyzed and which provides an intuitive, correct, precision way of all existing non-conformities [10]. Where the situation allows, in the activity of designing a maintenance system, it is desirable to obtain real-time processing of all existing data, which involves the immediate introduction into the system of all messages received from terminals [3]. The use of artificial expertise increases the possibilities offered by human reasoning, with obvious advantages over human agents, one of them referring to its permanent character [12].

2. APPLICATION METHODOLOGY

The project control system includes the measurement of consumed resources, the level of achievement, comparing the results with projections and standards, and developing the initial elements for diagnosis and preplanning. The control applied in the project development stage provides for three essential stages to achieve or exceed the proposed targets: a) measuring progress towards achieving the objectives; b) evaluating the content that must be covered in the future; c) applying corrections.

Responsibilities established for process control are establishing research objectives, implementing standards and guidelines for corrective actions, and establishing a monitoring system to provide feedback on progress and how directives are being followed. The quality factor is a defining element when selecting the optimal project variant, but obviously, it must also be correlated with the other factors: domain, cost, time [13]. The assessment factors are meeting the proposed deadlines, the presentation of the project and its success from the point of view of the product's viability, the durability of the resulting product and obtaining the minimum operating or maintenance costs [5]. On the other hand, influences such as: rapid technological development, dynamic product supply on the market, the abundance or poverty of material and energy resources can influence over time the project's development, use or post-use projections.

The primary, main purpose of change control is to ensure the smooth and continuous operation of applications, respectively of the expected evolution [11]. Figure 1 illustrates the main guidelines necessary for the implementation of the innovative process of applying the methodologies specific to maintenance plans. Effective management of the software program throughout its operating cycle requires a well-designed cost and control system, developed and implemented to obtain immediate feedback with which updated progress or resources can be compared against objectives set during the stages of planning.

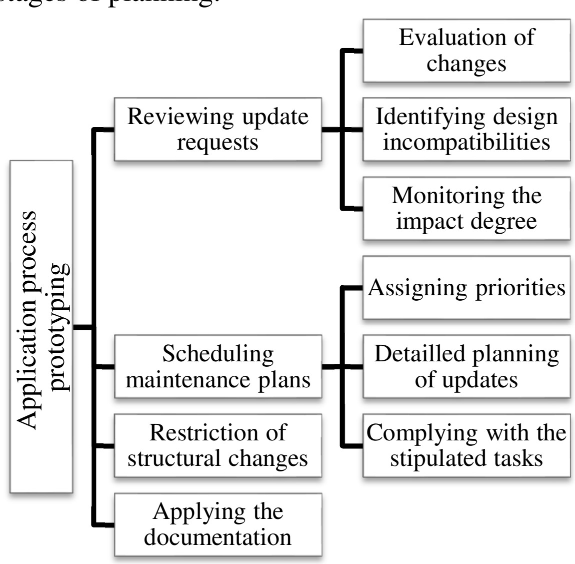

Fig. 1. Directives related to process prototyping.

There are certain guidelines necessary to verify the predictive maintenance system, such as: ensuring that the system is properly configured to provide accurate and relevant data about the status of the systems, validating the accuracy and relevance of the data collected by the maintenance system, verifying the correctness of the models used.

The notification system plays an important role in validating the system through proper operation and timely delivery of relevant information. The prescriptive maintenance system must be adequately integrated with other systems, such as equipment management systems and those related to technical asset management.

In addition, a project may include legal, economic, technical or environmental impact data and analysis. A proposed schematic form of the project structure to be implemented is presented in Figure 2.

A modern maintenance management implies a continuous concern for increasing efficiency, expressed through two categories of indicators: technical and economic. Improving performance in maintenance is a particularly complex process, which involves the training of material and human resources to achieve predetermined objectives. To ensure the preservation of the productive potential of the enterprise, the maintenance responsibilities are embodied in actions aimed at:

- The permanent diagnosis of the technical condition of the equipment;
- Fixing the detected malfunctions;
- Repairing and putting equipment back into operation in case of breakdown;
- Carrying out activities of installation, and arrangement of new maintenance methods to optimally use the new equipment;
- Identifying the optimal software architecture design solution.

3. INNOVATION MODEL PROTOTYPING

The prescriptive model involves obtaining instances, decisions, and outcomes. To obtain clear and correct rules from an IT point of view, it is recommended to develop and use an inference engine specific to reasoning procedures. In turn, the reasoning module is directly influenced by a sub module specific to the verification of justifications.

The obtained prescriptive model will be used for the full implementation of the system and the procedural norms of prescriptive maintenance. The logical representation of prescriptive maintenance procedures and mapped specific implementation tasks will contribute to the development of a characteristic specification base. At the same time, the periodic and procedural updating of the implementation of the prescriptive maintenance system is a necessary step to integrate the emerging new elements.

Analyzed systems will be monitored and modelled to obtain a reference benchmark model. Of course, the entire modelling process will be subject to a verification step provided in the processing evaluation component. The partial results obtained will be integrated into the machine learning process based on the algorithmic design. Also, the architecture must be flexible and scalable, so that it can be adapted to the changing needs of the proposed model.

3.1. Description of the process development

Rapid prototyping brings its contribution in the case of developing a demonstrative prototype, but also in improving the expansion of the project. The next step consists in the complete design of the software program. The development of a knowledge base is a fundamental step because it integrates the multitude of data to be processed later. This stage is followed by the integration of all sub-modules, components and technologies in a viable manner to obtain an optimal expected result. Of course, product installation and use are key elements of the implementation phase.

Furthermore, field integration and testing become much more accessible considering obtaining partial results in the desired context. Software engineering is not limited to initialization, development and implementation, but also considers the exploitation, maintenance, updating of the system and its periodic evaluation.

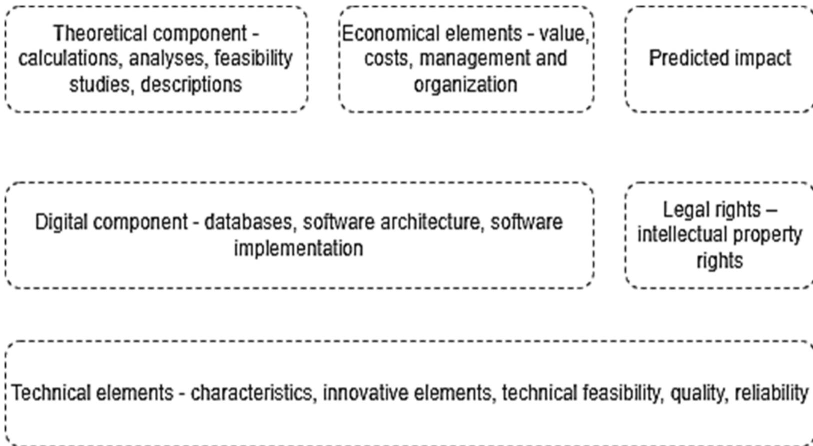

Fig. 2. Defining elements specific to the process components.

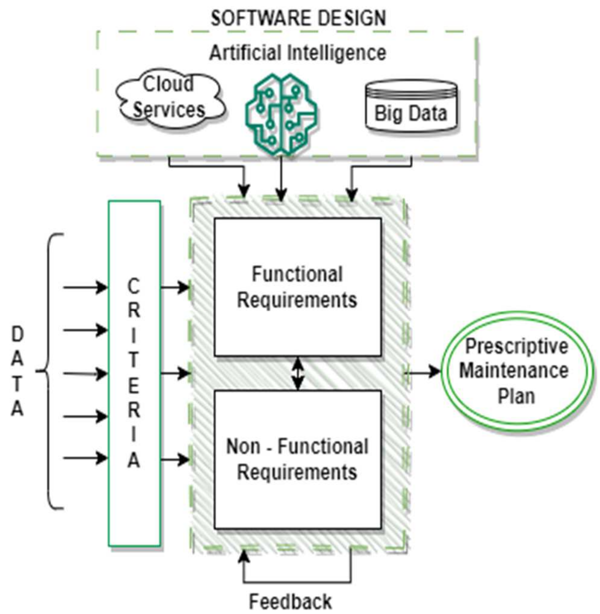

Fig. 3. The proposed software architecture.

To obtain the desired prototype, the need to create specific software architecture for digitization, such as the one illustrated in Figure 3, is noted. In the specifics of the proposed problem, the conceptual architecture refers to the way the system components are organized and understood, including the purpose, the relationship between them and the way they function as interconnectivity. The proposed architecture provides a perspective on the system, facilitating decision-making regarding its design, implementation and maintenance.

The architecture of the maintenance system may vary depending on the specific needs of each application, but generally includes the following components:

- A module that integrates advanced computing technologies, such as Cloud Services, Artificial Intelligence algorithms and Big Data – generically called Software Design;
- Data selection filters;
- A component that integrates both the functional and the non-functional requirements.

The architecture of the maintenance system shown in Figure 3 will allow integration with other relevant systems, such as the activity management system and the inventory management system. Also, the proposed architecture must be flexible and scalable, so that it can be adapted to the changing needs of the future system. Advanced data analysis includes the integration of Cloud technologies and data extraction algorithms through Data Mining techniques. Analyzed systems will be monitored and modelled to obtain a benchmark reference model. The partial results obtained will be integrated into the machine learning process based on the algorithmic design.

3.2. Conceptual model applicability

The goal of designing an effective architectural design for prescriptive maintenance is to maximize the availability and performance of systems by preventing problems and minimizing downtime while reducing costs and improving quality. At the level of requirements analysis, intermediate stages such as requirements specification, verification and validation of the results intervene.

In addition, the stage related to the design of the system is an elaborate one having direct implications with multiple other sub modules that communicate with each other towards obtaining and initializing the implementation of the project. Depending on the result of the functional requirements analysis, the appropriateness of their implementation will be determined so that this decision-making level will be taken within the decision-making component.

The development of test procedures and the realization of test cases will have repercussions both in the design and in the integration stages. Table 1 provides an analogy between a reference model specific to software engineering and a proposed model for implementing the innovative model.

Operation and exploitation, maintenance and development of the system is the stage that follows the conversion and installation of the new system, after passing the installation test, marking the moment of putting the system into operation, with a view to current operation and exploitation. Maintenance is carried out by setting the current state in the parameters designed and tested at installation in making the change or improvement, in hardware, in software, in procedures and documentation to eliminate errors, to satisfy new requirements or to increase operational efficiency.

Table 1

The defining comparative stages of the specific innovation process.

The reference model	Industry 4.0's particular model
Defining	1. Initialization 1.1. Assessment of needs 1.2. Establishing alternative solutions 1.3. Requirements consolidation
Planning	2. Analysis and design 2.1. Defining the development strategy 2.2. Carrying out the feasibility study 2.3. Establishing the resource requirement
Execution	3. Product development 3.1. Prototyping 3.1.1. Conceptual model development 3.1.2. Development and testing 3.1.3. Complete design 3.2. Deployment 3.2.1. Component development 3.2.2. Integration and evaluation 3.2.3. Installation and usage
Verification	4. Post-implementation 4.1. Technical exploitation 4.2. Maintenance and upgrade 4.3. Periodical assessment

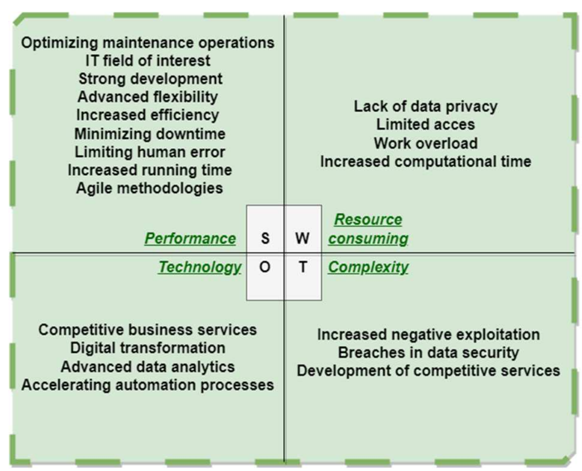

Fig. 4. The SWOT analysis of the digitalization process.

At the same time, as a stage related to the architectural and detailed design of the system, the component for marking the traceability of existing changes at the level of monitored equipment and at the level of product updates is designated. The actual implementation of the system provided as a software project has as its purpose the creation of functional components to be integrated and tested.

4. EFFICIENCY ANALYSIS

One of the basic requirements for products' manufacturing, with an appropriate quality level is the adequate organization of all the expected maintenance stages. Thus, idle times will be reduced and the entire manufacturing process will be increased. Also, compliance with the technological discipline will include the adoption of modern technologies. Decisions regarding ensuring an optimal relationship between manufacturing needs and reality intervene from the design phase. The interdependence of all components must be considered due to the implementation flow.

Selection criteria must consider specific applications, technology, quality, values of important parameters during long-term operation and reliability [3]. If the system under study is complex and intended for several functions, one and the same sub-assembly could participate in several other roles; so that the relative importance of each function, the role of each subassembly will allow the weighting of the various components in this allocation of prescriptive maintenance.

The ultimate purpose of data processing is to provide valuable information as well as to make better decisions based on it [15]. Achieving a digitization process depends on how accurately the specifications are defined. Until the basic design configuration is validated, the specifications are under constant revision. The requirements must clearly show what needs to be achieved in the product. Therefore, only those fundamental requirements for the system being designed should be taken over.

A practical method of analyzing both internal and external factors, which may appear at specific moments of time, is represented by the SWOT analysis illustrated in Figure 4. The most important strength is the performance of the whole innovative ensemble.

In addition, the novelty character is accentuated by a sharp development in the sphere of automations and agile methodologies. Weaknesses include high resource consumption and implicitly high time due to high-level processing. As opportunities of the innovative digitization process are the technological achievements in the upward plan, the services offered by the competitors in the market but also the digital transformation. The threats consist of the possibility of negative exploitation within the post-implementation stage.

Among the factors favoring the implementation of a prescriptive maintenance system, the following can be mentioned: free competition, which implies the permanent adoption of measures to improve current performances, the evolution of the technical and technological field, modern management methods, the desire for optimal exploitation of the equipment, the existence of a coherent implementation program.

Defining prescriptive maintenance requires careful planning, a consistent set of data so that maintenance becomes operational [8], an appropriate reasoning process, and the implementation of a machine learning mechanism that takes all previously obtained data and generates guidelines for future activities [8]. In the technical sphere of the project, the process of technological innovation thus intervenes, through which it is desired to obtain an integrated, innovative system in the field of maintenance.

The limitations of the innovation process of digitalizing prescriptive maintenance programs are defined by the technical characteristics of the hardware resources used. At the same time, data processing times can be limited to the minimum possible, but not eliminated, due to the integrated mechanical, technical or software resources.

5. CONCLUSION

The architecture of a maintenance system refers to how the system components are organized and work together to support its maintenance activities. The purpose of prescriptive maintenance system design is to ensure efficient operation and support business objectives by reducing costs, optimizing equipment availability and improving performance. Prescriptive IT systems maintenance refers to the use of advanced analytics and Artificial Intelligence technologies to monitor and predict system problems before they occur and initiate proactive maintenance actions. This process allows potential problems to be identified and preventive measures taken before they affect system performance or availability. The introduction of new technologies in the process of software development and hardware updating aims to develop new innovative products with improved quality, which are efficient and to provide services with high added value. In the same vein, this article submits to the research started within the university doctoral studies, bringing value by highlighting the current stage of the applied maintenance processes.

In the stage corresponding to the analysis and monitoring of the results, the obtained results will be analyzed, it will be tested if these results are at least close to the predicted ones. In the monitoring stage, certain components of the process can be identified that we did not consider during implementation or that did not actively intervene in the modification of the implementation plan, not affecting the anticipated results. In the case of artificial expertise, the information, once acquired, is permanently available to the user. Another advantage of using Artificial Intelligence is related to its ease of transfer. In the case of artificial expertise, documentation is much easier, while in the case of human expertise it is extremely difficult, requiring time and, in addition, it is imperative to verify the decisions made. Compared to human expertise, artificial expertise enables the acquisition of more consistent results and more security against vulnerabilities.

The critical examination of the obtained data has, in the case of information systems and in the case of the application of the corresponding maintenance processes, an overwhelming significance. Thus, it can be said that, in fact, the effectiveness of the entire system is determined, for the most part, by the way and degree of application of this analysis, taking into account both the favorable and unfavorable aspects. The current changes in management information systems imply the increasingly imperative use of knowledge at the expense of too large amounts of private data. Intelligent systems offer the possibility of combining the potential of database technology, fully matured and highly efficient in numerical processing, with knowledge base technology specialized in symbolic processing.

Considering the multitude of factors that support the development of the latest generation technology, it can be easily stated that there is still the possibility of developing innovative products and services, with a major impact on the continuation of the current digitalization process. Completing the steps described in the previous chapters could lead to major extension points, such as the development of various technological specialty areas. At the same time, there is the possibility of developing an intelligent software agent that automatically processes all knowledge and provides a basis for specialized decision support in engineering.

A possible direction of development consists in the integration of modules related to Cloud technologies directly into the basic architecture of the industrial system, without requiring subsequent updates. Current process innovation can perform multiple tasks, such as interpreting the results of maintenance plans as input to a future process analysis. Thus, the applied maintenance plan can be improved by processing and selecting parameters objectively, focused on results.

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, https://doi.org/10.1016/j.jik.2018.07.001

[2] Canito, A., Corchado, J., Marreiros, G., *Bridging the Gap Between Domain Ontologies for Predictive Maintenance with Machine Learning*, Trends and Applications in Information Systems and Technologies, WorldCIST 2021, Advances in Intelligent Systems and Computing, vol 1366, Springer, Cham, pp. 533-543, ISBN 978-3-030-72650-8, 2021, https://doi.org/10.1007/978-3-030-72651-5_51

[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, doi: 10.1109/MIM.2018.8573590

[4] Grijalvo, M., Pacios, A., Ordieres-Mere, J., Villalba-Diez, J., Morales, G., *New Business Models from Prescriptive Maintenance Strategies Aligned with Sustainable Development Goals*, Sustainability, vol. 13 (1), 2020, doi: 10.3390/su13010216

[5] Iung, B., *De la maintenance prédictive à la maintenance prescriptive: une évolution nécessaire pour l'industrie du futur*, Conference on Complexity Analysis of Industrial Systems and Advanced Modeling, 2019, https://hal.science/hal-02126720

[6] Jay, L., Hossein, D., Shanhu, Y., Behrad, B. *Towards an intelligent maintenance optimization system*, Procedia CIRP 38, pp. 3-7, 2015, doi: 10.1016/j.procir.2015.08.026

[7] Mancini, A., Paolanti, M., Romeo, L., Felicetti, A., Frontoni, E., Loncarski, L., *Machine Learning approach for Predictive Maintenance in Industry 4.0*, EEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA), vol. 14, pp. 1-6, 2018, doi: 10.1109/MESA.2018.8449150

[8] 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, doi: 10.25073/0866-773X/97

[9] Nadakatti, M., Ramachandra, A., Santosh Kumar, A. N., *Artificial Intelligence-based condition monitoring for plant maintenance*, Assembly Automation, vol. 28, pp. 143-150, 2008, doi: 10.1108/01445150810863725

[10] Pinciroli, L., Baraldi, P., Zio, E., *Maintenance optimization in Industry 4.0*, Reliability Engineering & System Safety, ISSN 0951-8320, 2023.

[11] Pospieszny, P., *Software estimation: towards prescriptive analytics*, Proceedings of the 27th international workshop on software measurement and 12th international conference on software process and product measurement, pp. 221-226, 2017, doi: 10.1145/3143434.3143459

[12] Sun, Y., Can, R., Yang, Z., Zhiquana, Y., *AI-based Prescriptive Maintenance for Sustainable Operation*, 13th Conference on Learning Factories, CLF 2023, SSRN 4457075, Singapore, 2023.

[13] 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.

[14] Ungureanu, N., Ungureanu, M., *System of Predictive Maintenance*, Scientific Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology, 2015

[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, doi: 10.1080/00207543.2018.1444806

Analiza inovării procesului de digitalizare pentru dezvoltarea planurilor de mentenanță prescriptivă

Un management modern al activității de mentenanță presupune o îndelungă preocupare pentru creșterea eficienței, cu scopul atingerii unor obiective prestabilite. Schimbarea tehnologică rapidă a pus accentul pe dezvoltarea proceselor inovative necesare implementării planurilor de mentenanță prescriptivă. Inovarea procesului de digitalizare impune modernizarea facilităților, competențelor și tehnologiilor utilizate pentru buna funcționare a tehnicii în uz. Bineînțeles, la nivelul inovării de proces se vor lua în considerare atât multiplele tendințe ale pieței tehnice, cât și cadrul adecvat de implementare a proiectului. În această ordine de idei, digitalizarea sporește atât procesele de automatizare cât și interconectivitatea elementelor de producție. Planurile de mentenanță prescriptivă pot fi definite inclusiv prin intermediul ingineriei software, având scopul de a asigura funcționarea optimă a sistemului în cauză, de a contribui la asigurarea disponibilității sistemului, de a optimiza consumul resurselor și de a preveni uzura sistemelor. Acest studiu prezintă prototipizarea modelului de inovare bazată pe proces, în contextul mentenanței prescriptive. Pentru evidențierea elementelor de digitalizare, au fost folosite concepte specifice ingineriei software, precum și includerea tehnologiilor computaționale avansate.

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.