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R e v i e w

of the doctoral dissertation by Dineshkumar Musalekar

entitled "**New approach to dynamic management of technical knowledge to construct a smart and flexible Die Casting Mould Manufacturing towards intelligent manufacturing**"

1. Problem Area

The doctoral dissertation under review addresses the dynamic management of technical knowledge (understood as the continuous acquisition and use of knowledge, together with the automatic updating of the knowledge base) in the design and manufacture of die casting moulds and in the production of castings using these moulds. The Candidate focuses on integrating the technical knowledge of design engineers, process engineers and operators (including explicit and tacit knowledge of the production process, its parameters and operating principles) with data recorded by machines and sensors and information from ERP and MES systems. This integration is intended to enable ongoing assessment of the production process, prediction of the quality of manufactured parts, and decision support concerning the course of the process.

The management of technical knowledge and its use in manufacturing processes have been studied for many years, yet remain highly relevant. The development of Industry 4.0 and subsequently Industry 5.0 has extended research on process automation to include human-centric systems. In such systems, humans are not merely recipients of algorithm-made decisions but participate in knowledge acquisition, supplementation, and verification, as well as in decision-making. The growing interest in this topic is evidenced by more than 3,000 publications on Industry 5.0 indexed in the Scopus database over the decade preceding the dissertation's submission (2015–2025).

More broadly, an important line of research seeks general methods and models of technical knowledge management that can be adapted to different manufacturing processes. The premise underlying this research is that combining employees' tacit knowledge with explicit knowledge recorded in documentation, information from ERP and MES systems, and data recorded by machines and sensors can improve process efficiency, in particular by enhancing product quality, shortening production time and reducing production costs. Existing solutions demonstrate the usefulness of individual sources of knowledge and data, but generally cover only selected elements of technical knowledge management. Monitoring systems focus on acquiring process data, predictive models on predicting specific states or product properties, and knowledge management systems on storing and sharing previously codified knowledge. These solutions generally neither integrate these functions with employees' tacit knowledge nor provide a feedback mechanism that enables knowledge to be verified, updated and reused during the manufacturing process. Consequently, process data, explicit knowledge and employee experience often remain separated, while the results produced by predictive models are not directly incorporated into ongoing technical knowledge management. An open research issue is therefore the development of a coherent approach that integrates the acquisition, representation, verification, updating and use of technical knowledge while remaining adaptable to different manufacturing processes. This difficulty arises from the complexity and diversity of these processes, the different sources and structures of data, the various forms of expert knowledge representation, and the diverse criteria used to assess efficiency. Methods developed for a specific production line cannot always be applied directly under different manufacturing conditions. A key issue in this context is distinguishing the general principles of technical knowledge management from solutions specific to a particular process. The processes examined in the dissertation, namely the design and manufacture of die casting moulds and the production of castings, exhibit such complexity. Part quality, mould life and production efficiency depend on numerous interrelated design, material and technological parameters. At the same time, the knowledge required to select these parameters appropriately is distributed across technical documentation, information systems, machine records, and the experience of design engineers, process engineers and operators. The research gap identified in this way provided the direct motivation for the research presented in the dissertation. The research was therefore directed towards the development and validation, under industrial conditions, of an approach combining process data, (tacit) employee knowledge, predictive models and a feedback mechanism.

From this perspective, the problem considered in the dissertation can be reconstructed as follows. The problem involves distributed technical knowledge resources related to the design, manufacture and operation of die casting moulds and the casting production process. These resources include knowledge recorded in documentation and in ERP and MES systems, knowledge held by employees, and process data recorded by machines and sensors. Given these resources, the following question arises: What approach to the dynamic management of explicit and tacit technical knowledge (including its acquisition, integration, storage, updating and sharing) can enable production process monitoring and support decision-making aimed at improving production efficiency? In this context, the method sought should integrate these functions and enable the automatic updating of the knowledge base and predictive model on the basis of incoming data and information provided by employees.

In my opinion, the dissertation addresses an important and timely research problem. Its novelty lies in the manner in which heterogeneous sources of knowledge and data, together with mechanisms for updating and using them, are integrated within a system validated under industrial conditions. The research topic is justified both by its scientific value and by the potential practical application of the results in the design, manufacture and operation of die casting moulds and in the casting production process.

2. Structure and Content

The dissertation comprises 132 pages and consists of six chapters, a list of 70 numbered references, four appendices, a list of abbreviations, and lists of figures, tables and appendices. The bibliography primarily covers Industry 5.0, intelligent manufacturing systems, and applications of artificial intelligence in process monitoring. It includes one article co-authored by the Candidate and published in Advances in Science and Technology Research Journal (IF = 1.5).

Two principal parts can be distinguished in the dissertation. The first part, comprising Chapters 1–3, presents the research assumptions, theoretical foundations, and literature review.

Chapter 1 is introductory. It presents the context of technical knowledge management in the design and manufacture of die casting moulds and in the production of castings. Two scientific objectives, one implementation objective, two research questions, and the research thesis are formulated. The stated objectives and research questions define the general direction of the research. However, the research thesis raises some reservations. It states that "The integration of technical knowledge and AI-based models into a unified monitoring framework can significantly improve the dynamic management of mould quality towards intelligent manufacturing" (p. 18). It is not clearly specified what 'significantly improve' means in this context or which criteria should be used to assess 'mould quality'. Although Chapter 1 discusses quality and performance indicators such as OEE, TEEP, scrap rate, cycle time, mould life, and mould maintenance costs, these indicators are introduced only after the research thesis and research questions have been formulated, without clearly indicating which will be used to verify the thesis.

Chapters 2 and 3 discuss intelligent manufacturing systems in the context of Industry 5.0, the role of humans in collaboration with intelligent machines and information systems, and methods supporting the individual stages of technical knowledge management. Particular attention is paid to methods for acquiring, storing, converting and visualising knowledge, integrating data from sensors and ERP and MES systems, and applying deep learning. The literature review is largely descriptive. However, it lacks information on the criteria used to select the publications under review and does not provide a synthetic comparison indicating which technical knowledge management functions are already available in existing solutions and which still need to be developed. Such an analysis would provide a clearer justification for the assumptions adopted in the subsequent part of the dissertation. Furthermore, the literature review lacks a critical discussion of how the correctness, reliability, and consistency of a dynamically updated knowledge base should be ensured. New knowledge derived from data recorded by machines and sensors, information provided by employees, or recommendations generated by artificial intelligence models may be incomplete, incorrect, or inconsistent with the knowledge already stored. Therefore, the system should not automatically incorporate every item of information provided by a human or every model recommendation into the knowledge base. The review does not discuss mechanisms for validating sources, detecting and resolving conflicts, approving changes, or protecting the system against the accidental or deliberate introduction of incorrect data. This issue is particularly important because the mechanism for continuously updating the knowledge base is one of the fundamental components of the approach proposed in the subsequent chapters.

The second part (Chapters 4–6), which contains the dissertation's principal research outcomes, presents the developed method for dynamic management of technical knowledge, its implementation as a decision support system, and the results of validation under industrial conditions.

Chapter 4 presents the Candidate's original method for technical knowledge management in the design and manufacture of die casting moulds and in the production of castings. First, the workflow of the processes under consideration is characterised, including requirements analysis, mould design and verification, mould manufacture, and its use in the casting production process. The chapter then discusses acquiring and storing data from IoT sensors and the ERP system, as well as employee knowledge. These resources are used to develop a technical knowledge base containing information on mould design, the properties of the parts produced, process parameters, and mould maintenance and repair. The final part of the chapter is devoted to the mechanism for converting the collected data into technical knowledge. The grounding of the proposed method in an actual industrial process deserves recognition. The detailed characterisation of this process provides a natural starting point for the development of a formal model of knowledge management in a manufacturing process. Such a model could specify the types of knowledge sources, the relationships among data, information, and knowledge, the rules for updating knowledge, and how it is used in decision-making. It would also make it possible to distinguish the general structure of the proposed approach from the parameters and rules specific to the manufacture of moulds and castings. However, no such formalisation is presented in the dissertation.

Chapter 5 is devoted to implementing the developed method as the AIMS (Artificial Intelligence-driven IoT Monitoring System) and validating it under industrial conditions. The system integrates data recorded by sensors installed on the die casting machine, the technical knowledge base, and an MLP model that predicts the quality of the manufactured parts. The predictions are converted into CONTINUE, ADJUST and STOP messages corresponding to three levels of process assessment. The experimental part presents the procedures for data preparation, model training, validation and testing, and compares the results obtained for different activation functions. Validation was conducted for the industrial production process of Mahle_PSA_FH components using data from 3,718 production cycles. The highest test accuracy, 99.06%, was obtained for the TANSIG function. The dissertation also assesses the effect of implementing the system on process efficiency, reporting, among other results, an increase in OEE from 71% to 78%, a 22% reduction in the scrap rate, a 13% increase in mould life, and a 16% reduction in the number of unplanned mould failures.

However, the model's usefulness should not be assessed solely by classification accuracy. In the proposed decision support mechanism, parameter values are modified in simulation until the desired quality class is obtained. The dissertation neither determines the computational complexity of this procedure nor reports the computation times. It also does not indicate how the number of parameters under consideration and the ranges of their possible values affect the time required to obtain a solution. Consequently, it remains unclear what problem scale the proposed approach can handle within the time constraints imposed by an actual manufacturing process.

Chapter 6 summarises the results and presents the declared contribution of the dissertation to the discipline of Mechanical Engineering. The developed solution is considered in the context of the fundamental principles of Industry 5.0, including human-centricity, sustainability and the resilience of production systems. Particularly noteworthy is the possibility of extending the AIMS to monitor environmental indicators, such as energy and material consumption, the amount of production waste and emission levels. Linking these indicators with process parameters, the quality of manufactured parts and efficiency indicators would enable the process to be assessed not only from production and economic perspectives, but also from an environmental perspective. Developing the system in this direction could provide a basis for multi-criteria decision support that accounts for the relationships and potential trade-offs among product quality, production efficiency and the reduction of its environmental impact. This is a promising direction for further research, directly related to the concept of sustainable production within Industry 5.0.

Overall, the structure of the dissertation is generally sound and allows the successive stages of the research to be followed-from the formulation of the research assumptions and the literature review, through method development and system implementation, to the presentation of the results and directions for future research. Despite the shortcomings identified above, it should be emphasized that the scope of the research, the development of the system and its validation under industrial conditions demonstrate the Candidate’s sound preparation and high level of competence.

3. Original Contributions

The principal contributions of the dissertation include:

1. Development of an original method for the dynamic management of technical knowledge, integrating employee knowledge with data recorded by sensors and information from the ERP system.

2. Development of a knowledge base concerning the design, manufacture and operation of die casting moulds and the casting production process.
3. Design and implementation of the AIMS decision support system, which predicts the quality of manufactured parts and identifies process parameter values for a specified quality class.
4. Planning and execution of experiments in an actual industrial environment, enabling validation of the developed system and assessment of the results using indicators characterising the quality and efficiency of the manufacturing process.

Taking into account the scientific and implementation contributions listed above, I consider that the Candidate has achieved the dissertation objectives. The results demonstrate the Candidate's competence in manufacturing process management, data analysis, applying artificial intelligence methods, designing and implementing decision support systems, and planning and conducting experiments in an industrial environment. They also demonstrate that the Candidate is capable of undertaking and independently accomplishing planned research objectives.

4. Comments and Remarks

General comments:

1. Section 5.1 presents the results of two experiments conducted on 130 and 167 samples, respectively. In each experiment, the number of samples for which changing the values of individual features caused the model to indicate the desired quality class was determined. The results are reported as the number of cases in which a given feature was modified. However, no in-depth analysis was conducted to determine whether a feature's more frequent occurrence indicates greater influence on product quality, or whether interactions among several features affect the result. This raises the question of whether the proposed approach can be used to identify, formulate and validate new rules and good practices for employees. If so, how should such rules be developed and incorporated into the technical knowledge base?
2. An important component of the knowledge base is design knowledge. The Candidate states that "The various factors involved here are – number of cavities, locations of the parting lines in the mould, position and size of inlet and position, size and number of outlets in order to have optimal time for flow of aluminium alloy and solidification to achieve both good quality and best cycle time" (p. 57). Chapter 4 also provides the following example of a design decision: "NO Coating on the Forming elements was chosen for this project as the design Engineers felt that with Dievar materials its not needed and probably after more than 50% of the usage of the mould PVD (Physical Vapour Deposition) coating using Chromium Nitride can be considered" (p. 58). This

type of knowledge includes spatial relationships, conditional rules, technological constraints, and the experience of design engineers, and therefore cannot be reduced to the parameter values recorded in successive production cycles. Does the developed AIMS enable such design knowledge to be represented, updated and used? If not, what components—for example, a rule-based layer, an ontology or a case-based reasoning mechanism—would need to be added to the system?

3. In general terms, the aim of the research was to develop a universal method for technical knowledge management that could be applied in companies operating in the automotive and metal industries. However, the validation covered only two similar cases involving the production of compressor components with similar materials, designs and technological processes. This raises the question of which elements of the proposed method are general and which are specific to the cases under consideration. What changes would be necessary to apply the method to a different type of part, mould, machine or manufacturing process?

Detailed comments:

The dissertation also contains editorial errors and incorrect internal references, as well as inconsistencies in the description of the data used in the experiments. Examples include the following:

1. The table of contents lists Sections 5.1–5.3 (pp. 3–4), whereas Chapter 5 actually comprises Sections 5.1–5.4. Section 5.2, "Implementation of the System in the Company", which appears on p. 87, is omitted from the table of contents. Consequently, the numbering of the following two sections is shifted in the table of contents.
2. In the list of abbreviations (pp. 5–6), the abbreviations "NLP" and "CNC" are each listed twice. The list also contains incorrect expansions or designations, including "LSMT – Long Short-Term Memory" instead of "LSTM", "MLP – Multilayer Preceptor" instead of "Multilayer Perceptron", and "PC – Persona Computer" instead of "Personal Computer".
3. On p. 85 (paragraph 2), the following reference is made: "Figure 10 illustrates the possibility of the simulation...", whereas the figure immediately below is labelled "Figure 9". Figure 10 does not appear until p. 95.
4. The list of references contains several duplicate entries. These are items 10 and 11 (p. 118), items 20 and 21 (pp. 118–119), and items 52 and 53 (p. 122). In each case, the publications have the same title, authors, and DOI.
5. On pp. 72 and 76, the data are divided into a training set (70%), a validation set (10%), and a test set (20%). However, the final paragraph on p. 75 states: "The training dataset was divided into training (70%), validation (15%), and test (15%) subsets." It is not indicated which split was ultimately used.

The examples presented above are not an exhaustive list of the editorial errors and inconsistencies in the dissertation.

5. Conclusion

In conclusion, I find that the doctoral dissertation under review by Dineshkumar Musalekar provides an original solution to the research problem through the development and validation, under industrial conditions, of an original method for the dynamic management of technical knowledge in the design and manufacture of die casting moulds and in the production of castings. The Candidate has demonstrated knowledge of the relevant literature and competence in manufacturing process management, data analysis, applying artificial intelligence methods, designing and implementing decision support systems, and planning and conducting experiments in an industrial environment. The comments raised in this review do not detract from the scientific value of the dissertation or from the assessment of its principal contributions.

In my opinion, the reviewed doctoral dissertation meets the requirements of The Act of July 20, 2018, Higher Education Law and Science (with later amendments) in the discipline of Mechanical Engineering, and I recommend that it be admitted to public defence.

Grzegorz Bocewicz