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Review of the doctoral dissertation of mgr. inż. Fredrick Wanyama Mumali entitled „A methodology for intelligent support in the selection of manufacturing processes based on Generalized Matrix Learning Vector Quantization neural network" prepared under the scientific supervision of:
Supervisor: dr. hab. inż. Joanna Kałkowska, prof. PP
Auxiliary supervisor: dr. inż. Michał Trziszka

1. Formal information

The formal basis for the preparation of this review is the letter of the Dean of the Faculty of Engineering Management, Poznan University of Technology dr hab. inż. Marcin Butlewski, prof. PP, dated 14 July 2025 regarding my appointment (in accordance with the Resolution of the Council for Academic Discipline of Management and Quality Sciences of Poznan University of Technology no 58/2024-2028 dated 30 June 2025) as a reviewer of a doctoral dissertation mgr. inż. Fredrick Wanyama Mumali entitled „A methodology for intelligent support in the selection of manufacturing processes based on Generalized Matrix Learning Vector Quantization neural network" prepared under the scientific supervision of supervisor: dr. hab. inż. Joanna Kałkowska, prof. PP, auxiliary supervisor: dr. inż. Michał Trziszka (field: social sciences, discipline: management and quality sciences).

2. Assessment of the selected research topic, objectives and hypotheses

The selected research topic is important and timely because it concerns the use of an intelligent system to support the decision-making process related to selecting a production process within an enterprise. This is done to increase industrial efficiency, strive to improve the quality of products offered, and ensure compliance with the concept of sustainable development. There is a justified interest in limiting the influence of subjective decision-making factors, relying on knowledge, taking into account specific product design requirements, and sustainable development goals. Research on the application of chosen AI methods to support

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the selection of production processes enables the expansion of the available solutions in this field, which can enhance the quality and objectivity of decisions, among other benefits, aimed at reducing production costs and improving operational competitiveness in a dynamic industrial environment.

The research undertaken is well-responsive to current industrial needs and trends, such as Smart Manufacturing, the principles of Industry 4.0, and Industry 5.0. In particular, attention was rightly drawn to the need to consider subjective decision factors and support decision-making in a changing environment, emphasizing the importance of proper collaboration between humans and machines. Industrial challenges were correctly identified and attention was focused on real-world production problems related to the selection of production processes, such as material selection, cost optimization, or process flexibility. The research addresses solutions that are currently underdeveloped in the available literature and the limitations of existing decision-making systems.

The author of this dissertation noted that the potential of selected intelligent solutions in the field of selecting and managing manufacturing processes has not been sufficiently explored. In this field, there is a need for flexible and adaptive decision-making support based on the results of processing massive amounts of generated data, often characterized by significant diversity, complexity, multidimensionality, and heterogeneity. The presented considerations enable the incorporation of previously less-noticed AI methods into the proposal of new solutions useful in process selection. Therefore, they provide not only theoretical and cognitive value but also significant practical value related to the numerous potential applications in real-world production environments.

The presented considerations concern solutions that have significant potential for improving key performance indicators in production. The research involves applying a method that enables the implementation of scalable and adaptive systems, which can be easily expanded as needed and flexibly adapted to various production contexts. The importance of the proposed research topic stems from its application to systems that support decision-making under conditions of uncertainty, where subjective human judgment is challenged by inconsistency and other significant limitations. The presented analytical results also consider the benefits of incorporating the principles of sustainable development and optimizing resource utilization. The proposed research topic also offers the opportunity for further continuation and advancement in research on intelligent decision-support systems in production management.

Models based on Learning Vector Quantization (LVQ) algorithms have long been recognized and valued in various applications due to their suitability in solving classification

problems. Research is warranted to explore the potential applications of further refined LVQ models and solutions based on them that exhibit increasingly improved properties. This dissertation focuses on Generalized Matrix Learning Vector Quantization (GMLVQ), which provides a foundation for building efficient and universal classification models useful for analyzing multidimensional and noisy datasets, often encountered when solving production management problems under conditions of uncertainty.

The research undertaken provides a compelling response to the existing need to develop interesting applications of new models based on modified and improved LVQ algorithms for use in production process selection and other production management problems. There are real gaps in the literature regarding solutions that enable the utilization of domain knowledge resources, limit subjective decision-making factors, incorporate sustainable development goals, and address product-specific design requirements, resulting in flexible and intelligent decision-making. The author of the dissertation noted these gaps and rightly acknowledged the progress in the development of AI methods and computational intelligence algorithms, identifying an opportunity for interesting research related to selected models based on a selected type of neural networks. It is worth noting the family of vector quantization methods and prototype-based supervised classification algorithms, with slightly different properties (related to, e.g., relevance profiles, matrix forms, and metric learning): LVQ, GLVQ (Generalized LVQ), GRLVQ (Generalized Relevance LVQ), RLVQ (Relevance Learning Vector Quantization), and GMLVQ (Generalized Matrix Learning Vector Quantization). GMLVQ was rightly chosen as the main research focus due to its universal nature, which creates significant application potential.

This research is motivated by the ongoing need to improve machine learning methods for selecting manufacturing processes effectively in conditions of increasing complexity, uncertainty, and the frequent imperfections of large empirical datasets. Additionally, there is a need to reduce human error and subjective factors that hinder objective decision-making, due to diverse personal attitudes and group thinking, which may not always align with the proper application of domain knowledge.

It is worthwhile to build on the extensive body of work on traditional LVQ models and on more recent developments in GMLVQ applications for analyzing complex patterns in multidimensional and incomplete datasets. Using GMLVQ can lead to the development of universal and more efficient models compared to those previously used. The literature review presented in this dissertation reveals a significant research gap, particularly in solving classification problems in the field of production management, resulting from the analysis of

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large sets of uncertain and noisy data. Solving these problems should be carried out while minimizing subjective decision-making factors (e.g., personal attitudes, prejudices, and cognitive biases) and objectively incorporating domain knowledge into the decision-making process. The choice of the research subject and the aim of this dissertation are therefore justified by the significant potential of the GMLVQ neural network in improving intelligent decision-making in the selected problem of manufacturing process selection.

The author of this dissertation accurately identified the research gap against the backdrop of the significant existing research on various methods for selecting manufacturing processes, including AI systems, expert systems, and multi-criteria methods. There is still insufficient research on integrated and holistic intelligent decision support systems that are based on specialized domain knowledge in production management and incorporate the concept of sustainable development, technological advancement, and a dynamic process approach appropriate for the uncertain and turbulent environment of manufacturing enterprises. Bridging the research gap involves considering subjective decision-making factors that influence the selection of production processes and developing a method for intelligent support in the selection of production processes based on advanced neural network models. Correctly identifying the research gap provided a valuable motivation for conducting research that is timely and important for the development of the theory and practice of process selection in production management within the discipline of management and quality science.

Research on various methods and models for selecting production processes has been evident in the literature for some time and has been undertaken by numerous scientists. The problem of selecting such a process is no easy task, as the decision space is extremely complex due to the multitude of quantitative and qualitative criteria, significant constraints, and the need to conduct analyses under conditions of uncertainty. The relevance of the chosen research topic stems from the growing importance of AI methods in supporting business management. The topic selection can therefore be assessed positively, and the research undertaken can be considered valid and interesting. The title of the dissertation is well-formulated and clearly reflects its content.

The use of selected neural networks is generally justified by their universality and decision-support capabilities, as well as their ability to analyze complex data with multidimensional and nonlinear dependencies effectively. In particular, GMLVQ methods are noteworthy because they solve classification problems based on learnable, interpretable relevance profiles of features, which is particularly important for analyzing noisy,

multidimensional production datasets and, to some extent, providing managers and production engineers with transparency in decision-making processes.

Reading the dissertation is somewhat difficult in places due to emerging doubts regarding the descriptions of some issues. In the Abstract, the subject of the research is described in two-fold form as follows: "first, it concerns the interplay between subjective decision factors and the use of domain knowledge in manufacturing process selection, particularly in the era of Industry 5.0, where manufacturing is re-imagined with a stronger focus on human-centric decision-making. Secondly, it concerns a methodology for the intelligent selection of optimal manufacturing processes based on GMLVQ neural networks." This outlines the general thematic scope of the dissertation: the interplay between subjective decision factors, domain knowledge, and the development of methods using advanced neural network models for selecting production processes in the context of Industry 5.0. At the end of subsection 1.2, he introduces this subject of the research and this time calls it "the research problem." However, this is not the research problem, as this description covers the broad area under investigation and does not specify the unresolved problem, e.g., what is missing in current approaches or why existing methods are insufficient. It is therefore difficult to find a clearly formulated research problem.

The dissertation goal is as follows: "develop and verify a methodology for intelligent support in selecting manufacturing processes based on the GMLVQ neural network, to alleviate subjective decision factors and leverage domain knowledge in addition to sustainability goals and the product-specific design requirements". Such a specific goal can be assessed positively.

The following two hypotheses also look good, their verification leads to original results and a clear indication of the author's own contribution to science:

H1: "Subjective decision factors, namely cognitive biases, personal preferences, and groupthink, contribute to the selection of inefficient manufacturing processes by limiting the effective use of domain knowledge in decision-making, which runs counter to the principles of Industry 4.0 and Industry 5.0".

H2: "An intelligent decision support methodology utilizing an enhanced Generalized Matrix Learning Vector Quantization neural network significantly improves the efficiency of manufacturing process selection by mitigating the collective impact of subjective decision factors such as cognitive biases, personal preferences, groupthink, and cognitive load".

More than ten sub-hypotheses were also formulated, the multitude of which facilitates detailed verification but does not positively affect the clarity of the arguments. The subsection devoted to the presentation lacks a brief explanation of what is meant by „efficient

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manufacturing processes" and how the efficiency can be measured and assessed in the analyzed context.

The research topic is interesting, well-chosen, and provides a solid foundation for a scientifically valuable dissertation topic. Its selection demonstrates the author's thorough understanding of the important and key challenges facing management and quality sciences, particularly those related to the management of manufacturing enterprises.

The wording used could have been more carefully considered. Presenting the main dissertation goal and accompanying detailed objectives in an appropriate place in the Introduction chapter would have increased readability and facilitated understanding of the work's content. The tasks listed in the Research objectives section helped guide the research work.

Despite some terminological doubts, the chosen research topic, the dissertation goal, and hypotheses can be assessed positively, as they enabled the implementation of research leading to significant theoretical effects in the field of management and quality sciences, as well as significant utilitarian effects.

3. Evaluation of the dissertation structure

The text of the dissertation is 209 A4 pages, a length that can be considered appropriate for this type of work. The length of the work clearly demonstrates the doctoral student's ability to organize and select the collected information effectively.

The structure of the work is coherent, logically arranged, and relatively well-chosen in the context of the thesis's title. This structure consists of an introduction, four chapters, conclusions, an extensive bibliography, and lists of figures and tables. It is appropriate and reflects the stated goals, subject matter, and scope of the research. However, the absence of keywords in the abstract, which are required in doctoral dissertations, is noteworthy. There is also no appendix, which would have been an appropriate place to include more detailed information regarding the empirical research and larger tables and figures. Moving these to the appendix would have improved the readability of the main body of the dissertation.

The order of content presented in the Introduction chapter raises some concerns, as it is crucial for presenting the research context, justifying the topic's significance, and introducing the reader to the research logic. It should begin with a justification for the dissertation's topic, followed by a clear statement of the dissertation's purpose and a presentation of the research hypotheses that define the subject of the study. A discussion of the research methodology and a presentation of the dissertation's structure are appropriately placed at the end

of the introduction. However, other elements of the description raise concerns, as they do not always ensure adequate clarity of discussion, logical reasoning, or coherence in demonstrating the research's scientific value.

The introduction chapter begins correctly with a presentation of the topic's origins, justification for addressing the dissertation topic, and a definition of the research gap. After presenting the broad research context and identifying the research gap, the research problem, research objectives, and research hypotheses should be defined. In the dissertation, these elements are presented in a different order, with some overlap, and the clarity and logical flow of the discussion are not ensured. There is an unclear distinction between the dissertation's goal and the research's overall objective. Furthermore, the order of presenting the research hypotheses first is incorrect, followed by a vague description of the research problem and research objectives.

Despite certain shortcomings, the dissertation's structure generally meets the requirements for doctoral theses.

4. Substantive evaluation of the dissertation

The research presented in this dissertation is worthwhile and was carried out to an acceptable standard, utilizing appropriate research techniques in both the theoretical and practical sections. The theoretical foundations for research on intelligent support in selecting production processes are well-chosen, and the arguments are convincing. The literature review was conducted appropriately and comprehensively, covering the discussed topic and drawing on carefully selected sources that provide a suitable foundation and support for the formulation of hypotheses. The literature review involves analyzing publications that present research results in papers at international conferences, in prestigious journals, or submitted for publication. The theoretical section of the dissertation provides a solid foundation for presenting the empirical research results.

The first chapter presents an introduction and the background of the research, which includes justification for addressing the dissertation topic, hypotheses, research objectives, study methodology, and dissertation structure. It provides a clear justification for the research topic and the importance of considering the influence of cognitive biases, human factors, and domain knowledge in the selection of manufacturing processes. This chapter could have provided a more concise and understandable description of the research problem, but the dissertation goal is presented correctly. The introduction chapter lacks a concise description of the method for hypothesis verification, along with a brief justification of the research

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methods and tools used, which may raise some doubts regarding the method for hypothesis verification.

The second chapter discusses the theoretical framework and empirical insights on manufacturing process selection, as well as the analysis of subjective influences on process selection using empirical data. The considerations are interesting in the context of the previously formulated hypotheses. The results of analyses of the impact of cognitive biases, personal preferences, and groupthink on decision-making processes are valuable. The utilitarian implications of the dissertation are reinforced by considerations regarding the limitations of decision-making processes.

Chapter three presents the results of a systematic literature review on intelligent support in the selection of manufacturing processes over the past decade, as well as the applications of intelligent methods to support this process. The review highlights neural networks, fuzzy logic, genetic algorithms, and GMLVQ as promising approaches that can significantly complement existing systems. Unnecessarily, terms referring to various purposes unrelated to the aim of the dissertation are repeatedly used.

Chapter four presents the essence of GMLVQ and the results of a literature review on this algorithm, particularly its theoretical foundations and applications in manufacturing process selection. Considerations are included regarding the possibilities of improving decision-making processes through the flexible adjustment of feature importance and the processing of complex, multidimensional, and large empirical datasets. The importance of introducing new methods for manufacturing process selection stems from the increasing complexity and uncertainty of data. The discussion of GMLVQ is preceded by analyses of the literature on previously known methods, such as Kohonen's LVQ. The research encompasses literature from the past decade, indexed in Scopus, Web of Science, IEEE, and Springer databases. This literature review can be assessed positively, as it provides a solid theoretical foundation for the subsequently presented methodology for intelligent support in manufacturing process selection and the results of empirical studies. The theoretical part of the dissertation concludes with interesting conclusions regarding the potential for further theoretical research and practical applications of GMLVQ in solving complex and multifaceted classification problems.

Chapter five begins the experimental section of the dissertation and is devoted to the application of GMLVQ algorithms to optimize manufacturing process selection. It describes the principles of conducting computational experiments, characterizes the empirical dataset used, describes the data preprocessing method, utilizes IT tools, and evaluates metrics.

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A significant strength of this chapter lies in the results of comparative analyses of GMLVQ and SVM models. SVM is a good classifier, achieving an accuracy of 94%. A 100% accuracy result for selected classifiers based on machine learning models is generally viewed with skepticism. The chapter lacks adequate justification for the reliability of GMLVQ accuracy at this value. Therefore, the reader of the dissertation may have doubts about whether overfitting occurred, whether the dataset used in the study was large enough to properly conduct the model training process, and whether the classification problem was too easy (trivial). Despite these critical remarks, this chapter contains several interesting research results that are crucial to a positive substantive evaluation of the dissertation. Among the research results obtained, the findings that deserve recognition are those important for managers and practitioners of production management, which may provide useful guidance on the desired directions for implementing new intelligent systems that support decision-making in the selection processes of manufacturing processes under conditions of uncertainty.

Chapter six summarizes the research findings and presents prospects for the development of research on the application of AI methods in the analysis and selection of production processes. Theoretical and practical implications of developing and validating a decision support system based on GMLVQ are presented, which combines human decision-making factors with objective, data-driven conclusions. The presented research results are interesting and can be positively assessed within the discipline of management and quality science. The dissertation provides a proper reference for verifying the proposed hypotheses and identifies the limitations of the conducted research, as well as potential directions for further research.

The author of the dissertation could have devoted more attention to preparing a bibliographic list with fewer errors.

While reading the content of the dissertation, the following questions arose, which, if addressed to the author, could form the basis for discussion:

1) How can the performance, accuracy, and reliability of machine learning models applied to production process classification be defined and quantitatively measured?
2) By what criteria and methodologies can the performance of GMLVQ-based classifiers be comprehensively evaluated and validated, taking into account the following parameters: precision, recall, F1-score, robustness, computational efficiency, and interpretability within computational experiments?

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3) On what factors does the accuracy of machine learning–based classifiers depend, and how can the attainment of one hundred percent accuracy in computational experiments be interpreted and justified?
4) How can the efficiency and effectiveness of manufacturing process selection be objectively assessed?
5) What is the optimization of manufacturing processes selection using the selected machine learning method?
6) How can the computational complexity and implementation effort associated with the selected model be evaluated in comparison with other AI models?
7) To what extent can the GMLVQ-based methodology be generalized to other domains of management decision support, and what future research directions emerge from the current findings?

5. Evaluation of the editorial quality of the dissertation

The dissertation is written in a relatively accurate and understandable style and is based on the appropriate terminology used in management and quality sciences. However, there are minor stylistic inconsistencies, some editing errors, and punctuation errors, which sometimes reduce the text's communicativeness. There are also some awkward repetitions. Proofreading was not carried out with due diligence, and there are unfinished sentences, e.g., at the end of the Introduction chapter.

Proper comprehension of the text of a dissertation is limited by the frequent occurrence of excessively long paragraphs. Instead, the text should be divided into short, coherent sections that form distinct wholes. Excessively long sections of text are difficult to read and easily absorbed. Excessive spacing between paragraphs can also be noticeable.

The Introduction and Conclusions sections are typically not numbered. The introduction of a three-level numbering system for chapters, subchapters, and sections is controversial, and it is accompanied by related errors in the second chapter.

Insufficient care was taken in compiling the final reference list. There are sometimes excessive gaps between individual items. The References section is not included in the table of contents. There is no separate and properly prepared list of internet sources used. There are incorrect bibliographic descriptions, e.g., for item 7: missing authors for the publication, 265: missing conference name for the paper, 311: duplicate author names, 321: the access date should be provided for the online source, 388: incorrect surname of one of the authors – it is Veen, but it should be van Veen.

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The chapters are well-balanced in length, and in this respect, there are no significant differences between them.

References to figures in the text are sometimes incorrect, with figure numbers and additional descriptions, such as "below."

Proper page breaks are not consistently used, and tables are sometimes unnecessarily split across adjacent pages.

Acronyms are sometimes incorrectly explained, and they should be explained upon their first use in the text. For example, the acronym ANN (Artificial Neural Networks) is not explained until page 50. It was not used frequently enough in the text.

6. Conclusion

The doctoral dissertation mgr. inż. Fredrick Wanyama Mumali entitled „A methodology for intelligent support in the selection of manufacturing processes based on Generalized Matrix Learning Vector Quantization neural network," provides a sufficiently original solution to a scientific problem, demonstrates the author's general theoretical knowledge in the field of social sciences, management, and quality sciences, and demonstrates the ability to conduct research independently. The dissertation has significant scientific merit, great practical potential, and meets the requirements for doctoral dissertations outlined in the Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws, Dz.U. of 2024, item 1571, as amended), and therefore I request its adoption.

Tadeusz Gruszyński