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Doctoral dissertation review

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Generalized Matrix Learning Vector Quantization neural network

written at the Poznań University of Technology
under the direction of
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1. The importance of the work's subject matter

The work focuses on the important management process of transforming Industry 4.0 to 5.0 processes. It takes into account organizational and process conditions and also indicates the changes that are a consequence of implementing Industry 5.0.

Current publications in this area, in particular:

- León, O., Puente, J., Fernandez, I., & Luna, M. (2025). Challenges in Transitioning from Industry 4.0 to Industry 5.0: A Multicriteria Analysis. *Journal of Industrial Integration & Management* , *10* (1).
- Dehghan, S., Sattarpanah Karganroudi, S., Echchakoui, S., & Barka, N. (2025). The integration of additive manufacturing into industry 4.0 and industry 5.0: a bibliometric analysis (trends, opportunities, and challenges). *Machines* , *13* (1), 62.

- Monferdini, L., Tebaldi, L., & Bottani, E. (2025). From Industry 4.0 to Industry 5.0: Opportunities, Challenges, and Future Perspectives in Logistics. *Procedia Computer Science , 253* , 2941-2950.
- Mourtzis, D. (2024). Challenges and opportunities of the transition from Industry 4.0 to Industry 5.0. *Manufacturing from Industry 4.0 to Industry 5.0* , 97-131.

They point to the importance of researching these processes and the determinants of human functioning in transition processes. Industry 5.0 is not just about technology, but above all, about returning to the central role of humans, personalizing production, and questioning the role of integrating advanced technologies: artificial intelligence and the Internet of Things, in the development models of Industry 5.0. These development models, in turn, generate new business models. based on the sharing of resources (devices and systems) and services based on their use resulting from intersectoral cooperation.

Therefore, I believe that the topic discussed in the doctoral thesis is important from the point of view of industrial development (transformation from Industry 4.0 to 5.0) and fits into contemporary trends in management development (the use of artificial intelligence to support decision-making processes).

2. The structure of the work and its evaluation

The work consists of six chapters. The first chapter presents the basic components of the research: hypotheses, research objectives, research methodology for verifying the hypotheses and achieving the work's objectives, and the organization of the work. Therefore, this section presents the key components of this chapter, both from the perspective of the reviewer and the reader: justification of the topic of this work, research hypotheses, research objectives, methodology, and structure of the work.

The second chapter is a theoretical-research chapter that reviews the literature on decision-making when selecting both traditional and additive manufacturing (AM) processes. An introduction and literature review on manufacturing process selection are provided to establish a theoretical framework and research sub-hypotheses regarding empirical observations when making decisions about manufacturing processes. The

empirical research methodology is also discussed. The Author presents survey research conducted by 27 small and medium-sized enterprises (SMEs) from March to July 2023. companies asking 12 questions regarding decision-making when selecting production processes. 355 responses were received. The collected responses were analyzed using three statistical tools: IBM SPSS version 26, RStudio 2023.06.0 Build 421 and SmartPLS4. A conceptual PLS-SEM model was also presented. developed with three latent variables: subjective human decision-making factors and domain knowledge. Spearman's rank correlation was used, with a nonparametric measure of strength and direction. variables.

Chapter 3 presents intelligent support for the selection of production processes. Therefore, the structure of this chapter includes both a literature analysis – a theoretical part (Introduction and related works on intelligent computational methods) regarding the use of intelligent technologies in the selection of production processes – and a justification and assessment of the usefulness of the Generalized Matrix Learning Vector Quantization (GMLVQ) method for the selection of production processes.

The theoretical part of this chapter incorporates the Author's systematic literature review. A comprehensive review of 93 studies published between 2013 and 2023 on intelligent methodologies supporting the selection of production processes was conducted. This is a significant achievement for the Author, demonstrating how various intelligent technologies can be used to support decision-making processes. The aim of this review was to answer three research questions posed by the Author.

The result of preparing the third chapter is the development of the fourth chapter, in which the selected GMLVQ method is discussed in detail from the point of view of its possible application to support the selection of production processes. Sixty-one studies published between 2015 and 2024 were selected for analysis. This chapter provides a detailed background on the GMLVQ algorithm, followed by a systematic review of the relevant literature. This approach provides a broad context for the algorithm's application and justifies its use in the Author's research. The chapter concludes with a discussion of the systematic review of the GMLVQ literature, along with implications, limitations, and future research directions in this area.

Chapter 5 presents the methodology for intelligent support in the production process. This chapter presents the application of GMLVQ in polymer processing process selection. Six research questions were formulated as part of the review. The chapter discusses the problem of GMLVQ selection and its possible applications. Next, the Author presents the experimental setup for intelligent decision support based on GMLVQ. This chapter summarizes the results of the Author's research in the form of a correlation matrix. The chapter also presents the possibilities of optimizing process selection parameters, along with a discussion in the context of production process selection.

is summarized in the sixth chapter: conclusions and future prospects , the status of verified hypotheses and the possibilities of integrating GMLVQ with decision support systems.

Notes on the structure of the work:

Dividing the work into six chapters and separating the theoretical parts into chapters two and four allowed the Author to separate the theoretical from the practical, but made it more difficult to understand the work's objectives. It might be worthwhile to divide this work into two areas resulting from the research hypotheses. These hypotheses constitute its backbone and should determine the adopted structure. This means that if we assume that two processes of verifying the presented hypotheses must be implemented, the structure of the work should reflect these processes. This also means that the first chapter should remain in its entirety. In chapter two, subchapters 2.1 and 2.2 should constitute the assumptions for conducting the empirical research described in chapters 2.3 and 2.4. Chapter three, in turn, should integrate chapters 3 and 4, with chapter three constituting the assumptions for selecting the GMLVQ. The discussion included there, while very interesting from the perspective of the research process, could demonstrate the determinants of the GMLVQ in the context of its usefulness in selecting production processes. However, I would divide chapter 5 into two parts: methodological and verification. In this case, the research processes described focus solely on verifying both hypotheses. These suggested changes are a consequence of the process of reading this work. After the first reading, the reviewer found it difficult to identify key research areas.

3. The research process and its evaluation

The research process, including all its components, is presented in Figure 1.1. It included three main research processes: theoretical analysis, empirical research based on the experience of survey respondents, and experimental research. The figure also presents the two main research hypotheses and indicates the process of their verification.

Analysis of Figure 1 shows that the first stage of the research, Figure 1.1 (1), required a general analysis of Industry 4.0 and Industry 5.0 processes, the importance of technological processes, and the place and role of humans in subjective decision-making regarding the selection of these processes. The possibility of supporting these processes with decision support systems is also demonstrated. This general analysis allowed for situating the research and justifying the purpose of empirical research. The Author conducted this research using a survey conducted in 76 companies (3), (4), and (5). The combination of literature review and empirical research allowed for the verification of the first research hypothesis, indicating limited decision-making capabilities regarding the selection of production processes. Research stages (3) and (4) in Figure 1.1 indicated the place and role of empirical research. These stages defined the research concept, which was then implemented through surveys and conclusions drawn that formed the basis for hypothesis verification.

In parallel, research was conducted to verify the second hypothesis, which involved an analysis of the literature on the use of decision support systems in the selection of production processes, as well as the place and role of intelligent methods and models supporting these processes. Independent analysis (in different chapters of this work) of these two literature sources allowed us to demonstrate, on the one hand, the role of decision support systems in the selection of production processes, and on the other hand, how these systems and the algorithms used to support the selection of these processes.

The goal of these two analyses was to identify the state of the art in the literature demonstrating the place and role of GMLVQ classification algorithms in decision-making. This selection of literature and the sequence of the literature analysis allowed for an assessment of the extent to which the GMLVQ algorithm could be used to support the

production processes selected by the Author. Therefore, after analyzing the potential use of this algorithm, the next stage of research was undertaken, which concerned the design and application of the algorithm in the experiment conducted by the Author.

The goal of this experiment was to design a system for intelligently selecting production processes. Therefore, a production process was selected, for which predefined data was used in the training and testing processes. This verified the methodology developed by Autor for selecting production process classifications. This methodology, presented in Figure 5.1, demonstrates the classification of processes using the GMLVQ algorithm. Thus, Hypothesis 2 was verified.

Notes on the research process:

I consider this research process designed to be correct. Its presentation in Figure 1.1 allows for a clear definition of the location and role of the research processes necessary to verify the first and second hypotheses.

I believe it would be worthwhile to consider where Figure 1.1 should be placed. This is a key description for the work, demonstrating the work's structure. The Author adopted the classic approach of placing this figure at the beginning of the work, but not describing it precisely enough. I also believe it would be worthwhile to consider a solution in which, when describing subsequent research processes in the work, references should be made to Figure 1.1. This figure very precisely defines the method of conducting the research. Sub-hypotheses, tasks, and objectives have been added in many places, which disrupt and somewhat disrupt the work's layout, as they seem to be posed arbitrarily. Research questions should be based on an analysis of the literature or hypothesis verification processes. If the Author, while carrying out a given research process, indicated that it was carried out in accordance with the marked stage shown in Figure 1.1, it would certainly significantly improve the readability of the work.

At this point, the question arises: what is the significance of these sub-hypotheses for verifying the research process, since Figure 1.1 so precisely depicts the research process? It also raises the question of the place and role of the presented objectives and

research questions, since verifying both hypotheses allows for a clear definition of what we actually expect from this work.

4. Resources for the implementation of the research process and their evaluation

In order to verify the hypotheses presented by the Author, it was necessary to isolate three main resources of this work: literature items mainly from the years 2014-2024, surveys obtained as a result of empirical research on the assessment of production processes and their selection methods, and data on the research process that allowed for the selection processes and parameters of testing and use of the GMLVQ algorithm.

To support this process, it was also necessary to utilize appropriate information technology. I consider the selection of resources to be appropriate, taking into account the literature review conducted. Regarding the selection of survey questions, the method of conducting the survey, and the obtained results, I also consider these processes to be appropriate, demonstrating the place and role of subjectivity in decision-making processes for selecting a polymer production process.

I also consider the selection of manufacturing process parameters to be appropriate. These processes included training and testing the developed solution: blow molding, injection molding, rotational molding, and thermoforming. The Author prepared a dataset containing 200 samples covering four processing methods and a total of 14 parameters, including size (m3), surface finish (R), tolerance, wall thickness, cycle time (s), precision, processing speed, labor cost, suitability for large batches, suitability for small batches, scrap generation, scrap recycling, and energy consumption. Thirteen parameters were considered in the study, as shown in Figure 5.2.

Notes on Research Process Resources:

I would like to comment on the scope of the literature. It seems that the analysis of the literature could have been limited to the last five years and shown to be comprehensive. I also consider the choice of processes, or as the Author puts it, techniques, for the experimental setup for intelligent decision support based on GMLVQ to be appropriate. It is also appropriate to verify the experimental results using a classifier such as a support vector machine (SVM) when selecting polymer processing techniques.

5. Overall rating

I consider the research process to be very interesting. It required considerable commitment from the Author. I consider the inclusion of theoretical (extensively conducted) and empirical research to justify the purpose of experimental research to be appropriate. One could argue that literature analysis is a sufficient assessment of the method for selecting production processes. The method used by the Author, which, in addition to literature analysis and the resulting conclusions, also includes the proposal of conducting survey research, enhances the credibility of this research. Obtaining subjective data that illustrates the method of selecting production processes allows for the proper determination of the purpose of conducting experimental research. It would be reasonable to assume that information technology significantly streamlines the selection of production processes through the use of decision support systems.

It turns out, however, that the selection process and subsequent interpretation of results require human involvement. This is why Industry 5.0 places such great importance on the place and role of humans, and the question arises as to how these decisions could be made objective, assuming we use an IT solution that analyzes knowledge using decision support systems. I consider this approach, presented in this work, to be valid and allow for the training and application of artificial intelligence models using this knowledge.

A deficiency of this work is the overly complex description, which involves the presentation of sub-hypotheses, tasks, and objectives. After all, the two hypotheses and their verification processes presented in Figure 1.1 clearly define both the structure and the research process. The introduction of tasks, sub-hypotheses, and objectives significantly disrupts the reading experience of this work, but it also makes it worthwhile to consider whether, at this stage of the research process, it would be insignificant to consider a subsequent version of this work, either in the form of an article or a broader scientific publication, that aggregates the material contained in the work. I am referring here primarily to theoretical and empirical analyses as the foundation or assumptions for conducting empirical and experimental research. This work then presents two main areas: assessing and identifying the place and role of humans in the selection of production

processes, and building a model enabling intelligent decision support through the use of the Author's own methodology.

The selection of predictive processes can be ensured through proper training and testing of the proposed algorithm. The vocabulary used in this work also seems important. Various terms appear in many places to describe the same concepts. It is unclear whether we are talking about a method, a methodology (Chapter 5), or an algorithm to precisely define the actual result of this work. It is also worth noting the frequent use of the term "optimal." The reviewer reminds us that optimality requires specifying a criterion. It is also difficult to understand the following sentence: The robust model performance, highlighted by 100% accuracy (Chapter 5). The statement (Chapter 5) "The proposed method can improve decision-making. Precise, optimized, effective, and efficient processes leading to high-quality, sustainable production" also requires the provision of performance and efficiency measures.

Undoubtedly, showing the importance and role of humans and their involvement in the process of building a process selection system and its verification is a key achievement of this work.

6. Evaluation of the work - Degree of fulfillment of the doctoral thesis criteria

The basis for the evaluation of the thesis (after the introduction, which shows on the one hand the importance of the thesis, then discusses the structure of the thesis and its evaluation, as well as the research process and its evaluation) should be referred to the criteria for the price of the doctoral thesis. Pursuant to Article 187 of the Act of 20 July 2018, "Law on Higher Education and Science", three statutory criteria for doctoral theses are adopted :

1. The doctoral dissertation presents the general theoretical knowledge of the PhD student in the discipline of management and quality sciences.
2. The doctoral dissertation demonstrates the doctoral student's ability to conduct independent scientific work.

3. The work constitutes an original solution to a scientific problem or a solution for the application of the results of one's own scientific research in the economic or social sphere.

I would like to address these criteria to evaluate this work. Considering the first criterion, I am absolutely convinced that the presented doctoral thesis presents general theoretical knowledge in the management discipline, specifying the area of building models for intelligent support of decision-making processes in Industry 5.0.

In the case of the second criterion, which states that the doctoral dissertation demonstrates the doctoral student's ability to independently conduct research, it seems to me that this work fully demonstrates that the doctoral student:

- Firstly, based on the analysis of decision support processes, it is able to define a research gap, but also for this research gap it is able to define the environment for conducting scientific research taking into account the proposed group of processes based on a set of research hypotheses.
- Then, they can apply this framework to their research. They can conduct the research and draw conclusions based on it. Looking at this thesis and its division into descriptive sections and research documentation, I can say that I would expect many doctoral theses to be similarly structured. This thesis resembles a well-written article, presenting the state-of-the-art, then proposing a research method, and then presenting the developed methodology, its verification, and drawing conclusions from the research.

Considering criterion 3 (indicating that the work represents an original scientific solution or a solution for applying the results of one's own research in the economic or social sphere), it should be stated that the very structure of the work indicates that this criterion is met. This work examines real-world support for manufacturing processes using the methodology proposed in the work. The obtained results demonstrate that this work has strong practical implications and can provide support for teams selecting production processes. It also appears that this work represents an original scientific solution to the problem of transforming Industry 4.0 to Industry 5.0. The scope of the research, its

coherence, the completeness of the hypotheses, and the processes of their verification indicate the need to distinguish this work.

7. Evaluation of the work - Conclusion

In conclusion, the synthetic evaluation of the doctoral dissertation of Mr. **Fredrick Wanyama Mumali, M.Sc.,** allows us to state that:

- The Author presented a scientific solution to the posed problem and achieved the intended goal of the work.
- He has demonstrated the ability to independently conduct scientific research in an area that requires significant knowledge and experience and is an area that is definitely difficult to research.
- The work demonstrates a very good knowledge of the literature and practical problems in the field of supporting software development processes and understanding them, as well as the Author's high level of knowledge in this field.
- The work demonstrates that the Author is able to analyze and document research results and has mastered the research apparatus.
- The dissertation contains original conclusions that are important for economic practice and constitute a significant scientific achievement of the Author.

The above conclusions justify the statement that the reviewed doctoral dissertation of Mr. **Fredrick Wanyama Mumali , M.Sc. Eng., M.Sc. Eng.,** meets the requirements specified in the Act on Academic Titles and Academic Degrees and I request that it be admitted to public defense.

Cezary Orłowski