

REVIEW OF PH.D. DOCTORAL DISSERTATION

Public defence

Candidate's name: **Rácz-Szabó András**

Title of the dissertation: **Development of machine learning, process modeling and optimization algorithms for supporting Industry 4.0 / Ipar 4.0-t támogató gépi tanulási, folyamatmodellezési és optimalizációs algoritmusok fejlesztése**

General opinion

The dissertation investigates the application of position data-based optimization, focusing primarily on industrial logistics, with an emphasis on its applicability within manufacturing facilities and warehouses. It introduces a novel network model, as well as optimization and estimation procedures developed by the Candidate. The models and procedures introduced aimed at identifying activity types, improving the accuracy of position data, and enhancing the efficiency of transportation tasks.

The Candidate's results are summarized in five research areas:

1. Description and comparison of RTLS systems.
2. Elaboration of a method for improving the accuracy of indoor positioning data.
3. Design of an algorithm to reduce idle runs.
4. Development of a modified DBSCAN method for identifying activity types; and representing activity types on a novel multi-level network graph.
5. Development of an MDP-based model to enhance the efficiency of production systems.

The dissertation is prepared with appropriate quality and according to professional standards. **The dissertation demonstrates the Candidate's ability to conduct independent research and creative work at a high standard.** The topic choice is timely and relevant. Enhancing the efficiency of logistic systems is not only in the interest of the companies involved but also serves the interest of society.

The Candidate has improved the dissertation considering my comments and suggestions given in the home defence.

Structure and style

The English-language dissertation, comprising 112 numbered pages, is divided into eight main chapters: Introduction, chapters corresponding to the five research areas, Conclusion, and Research questions and thesis findings chapter. At the beginning of the document, abstracts are provided in Hungarian, English, and German. At the end of the document, a List of notations, a Bibliography, and a List of figures and tables are provided.

The general structure is logical; however, the research questions should have been added in the Introduction chapter. Summarizing the thesis findings at the end of the dissertation is useful, however, the conclusion chapter could have preceded this chapter. Moreover, the readability would have been enhanced if the theses were explicitly stated in the summary subchapters of the chapters related to the theses.

The writing style is engaging, and the use of English is correct and clear. The typographical errors in the dissertation are not significant. The dissertation contains several abbreviations; their application is correct, and the use of nomenclature is particularly commendable.

The dissertation includes a comprehensive literature review, with a total of 229 references, six of which are own publications connected to the Candidate's theses. While the volume of reviewed literature is significant, the dissertation does not contain a dedicated literature review chapter. The literature is summarized in the Introduction chapter and/or the beginning of each thesis-related chapter. Accordingly, the Introduction chapter is excessively lengthy. Describing the research gaps identified during the literature review is useful. The literature review includes significant scientific publications related to the research area, and the Candidate formulated the research questions and identified research gaps based on the existing literature.

The dissertation is not overly elaborate and includes an appropriate number of figures and summary tables. The tables and figures effectively support comprehension.

Applied methods

The methods used in the research are appropriately complex and the methods are suitable for achieving the stated objectives. The Candidate demonstrates extensive methodological knowledge and applies the methods presented correctly.

The dissertation introduces complex, self-developed methods and procedures through numerous case studies, representing the practical applicability of the theoretical methods developed.

Candidate's scientific metrics

Based on the Candidate's MTMT and Tudometer metrics, the doctoral degree requirements are met. Publications have been produced within the research field and connected to the new scientific results. The Candidate has published eight papers, including three Hungarian-language conference papers, two English-language conference papers, and three English-language journal papers with Impact Factors. According to the Web of Science classification, the Candidate published these journal papers in one Q1 and two Q2 journals. The Candidate's Q score is 1.696, with a cumulative Impact Factor of 6.876 and 47 independent citations.

Scientific results

In the following sections, I will detail my observations and questions chapter by chapter, including specific remarks directly related to the theses themselves.

Chapter 2 – Thesis 1: Description and comparison of RTLS systems

In this chapter, the Candidate systematically reviews the available RTLS technologies based on an extensive literature review, presenting the technologies in detail and comparing them with a multicriteria analysis. This work is particularly valuable as it outlines the research directions for the Candidate. One of the strengths of the Candidate's PhD research is that it began with a systematic literature review. However, the Candidate's added scientific contribution is not entirely clear in this thesis.

During the defense, I recommend summarizing the added value (e.g., a structural model was developed based on the literature review). Moreover, a greater emphasis should be placed on highlighting the results (e.g., the achievable efficiency gains through the application of RTLS).

Chapter 3 – Thesis 2: Elaboration of a method for improving the accuracy of indoor positioning data

In this chapter, the Candidate presents a newly developed scientific method aimed at improving the accuracy of indoor positioning data, which can support the design and operation of logistical systems. The application of the method enables the acquisition of more precise spatial information, facilitating more efficient tracking and operational optimization in warehouse environments. The method was applied in a warehouse setting to study the movement of forklifts. Questions:

- During the interpolation process, did the Candidate consider assumptions other than linear interpolation? Why was the linear interpolation chosen?
- What potential development opportunities were identified through tracking the operational area of the vehicles?

Chapter 4 – Thesis 3: Design of an algorithm to reduce idle runs

In this chapter, the Candidate presents an optimization algorithm designed to reduce the empty runs of vehicles. As an innovative approach, the Candidate developed a multi-level network model to represent value-adding and non-value-adding vehicle movements. The identification of analogies between logistics and passenger transportation is particularly valuable, demonstrating the common root of these fields. The developed method was applied in a case study. Questions:

- What other methods, besides linear programming, could be employed to address the transportation problem? Did the Candidate explore heuristic methods, such as genetic algorithms or ant colony optimization, or consider the application of classical approaches like Dijkstra's algorithm?
- What was the justification for using Kernel-density estimation in the analysis? Could the Candidate have assumed a specific distribution (e.g., multimodal distribution corresponding to morning and afternoon peaks) for taxi usage patterns instead?
- How can the resilience of the system be defined in this context? What resilience indicators were considered, and what were their results in the case study?

Chapter 5 – Thesis 4: Development of a modified DBSCAN method for identifying activity types; and representing activity types on a novel multi-level network graph

In this chapter, the Candidate presents the modified DBSCAN method as a new contribution, which allows for the identification of value-adding activities. The method was applied in a warehouse environment to analyze forklift movement processes. It would have been more logical to reverse the order of Chapters 4 and 5, as well as Thesis 3 and 4. First, the identification of activities (covered in Chapter 5) could have been discussed, followed by the exploration of route options (discussed in Chapter 4). This restructuring would align better with the logical progression of the research. Questions regarding thesis 4:

- How are different activities (value-added and non-value-added) currently estimated in the profession? Is the process manual or does it involve any automated methods? Are any observation-based measurements or standard times used in the estimation process?

- How could the method be adapted for use with material handling equipment other than forklifts? What modifications would be necessary to apply the method to other material-handling equipment?

Chapter 6 – Thesis 5: Development of an MDP-based model to enhance the efficiency of production systems

In this chapter, the Candidate presents an analytical method and framework based on the application of Markov Decision Process (MDP) models for manufacturing and logistics processes. The model enables the identification of logical connections within a production line, including bottlenecks and excess capacity points. The method was demonstrated through a case study. The Candidate modified the thesis considering my comments given in the home defence. Accordingly, the coherency of the thesis has been improved. Questions:

- What are the cost implications of implementing these developments, including hardware, software, and integration costs? What return on investment metrics can be associated with these advancements? Under what conditions would it be worthwhile to undertake such investments?

Summary

The doctoral dissertation fulfills the stipulated academic requirements. The dissertation quality is high, and the conclusions drawn from the results are valid and well-founded. The discussion of the results is well-articulated and considers the findings of existing literature. The English and Hungarian thesis booklets also meet the requirements. They concisely summarize the Candidate's novel scientific contributions.

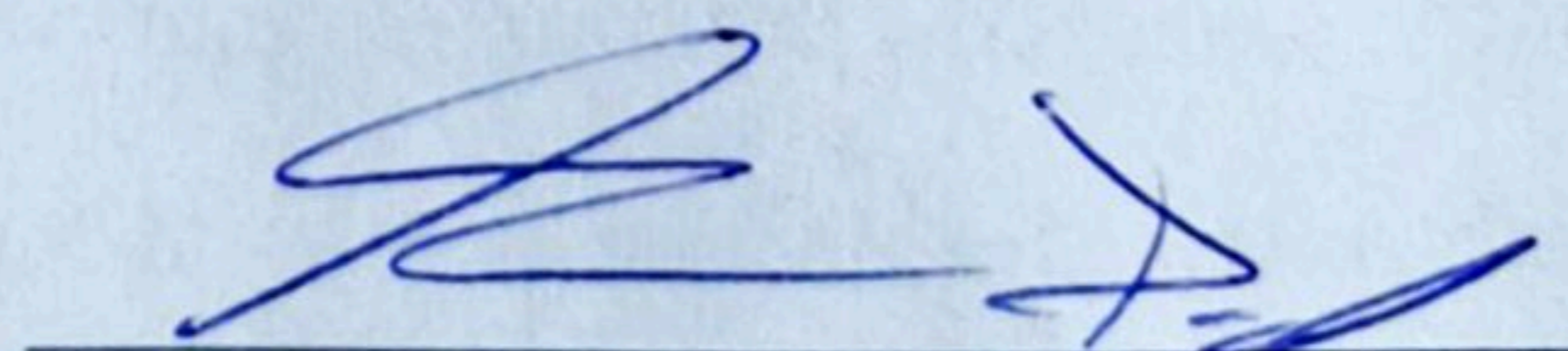
I acknowledge the five proposed theses as novel scientific contributions and accept them without the need for any modifications.

I recommend the dissertation for public defense.

Upon successful completion of the public defense, I support the awarding of the PhD degree to the Candidate.

Dated: Budapest, 20 December 2024

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Opponent