

## **Recenzja rozprawy doktorskiej**

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### **zatytułowanej:**

*New Directions in Robust Data Envelopment Analysis*

## **1. Problem badawczy i jego znaczenie**

The primary focus of this dissertation is on addressing the limitations of traditional Data Envelopment Analysis (DEA) methods. DEA is an essential tool for evaluating the efficiency of Decision Making Units (DMUs) in various sectors. The main research problem tackled in this dissertation is the need for a more comprehensive approach to evaluate the efficiency of DMUs, considering various input-output weight vectors and introducing robustness analysis. The research problem is undoubtedly of scientific importance, as it attempts to bridge a significant gap in the existing DEA literature. Moreover, the practical relevance of the problem is evident, given the wide-ranging applications of DEA in fields such as banking, healthcare, education, and transportation.

The dissertation consists of an extensive body of work comprising seven original publications that collectively explore the applications and implications of robustness analysis, primarily within the framework of Data Envelopment Analysis (DEA) and Ratio-Based Efficiency Models:

- [P1] M. Kadziński, A. Labijak, and M. Napieraj. Integrated framework for robustness analysis using ratio-based efficiency model with application to evaluation of polish airports. *Omega*, 67:1–18, 2017, DOI: 10.1016/j.omega.2016.03.003.
- [P2] P. Gasser, M. Cinelli, A. Labijak, M. Spada, P. Burgherr, M. Kadziński, and B. Stojadinović. Quantifying electricity supply resilience of countries with robust efficiency analysis. *Energies*, 13(7):1535, 2020, DOI: 10.3390/en13071535.

- [P3] A. Labijak-Kowalska and M. Kadziński. Experimental comparison of results provided by ranking methods in data envelopment analysis. *Expert Systems with Applications*, 173:114739, 2021, DOI: 10.1016/j.eswa.2021.114739.
- [P4] A. Labijak-Kowalska, M. Kadziński, I. Spychała, L. C. Dias, J. Fiallos, J. Patrick, W. Michalowski, and K. Farion. Performance evaluation of emergency department physicians using robust value-based additive efficiency model. *International Transactions in Operational Research*, 30(1):503–544, 2023, DOI: 10.1111/itor.13099.
- [P5] A. Labijak-Kowalska and M. Kadziński. Exact and stochastic methods for robustness analysis in the context of imprecise data envelopment analysis. *Operational Research*, 23(1):22, Mar 2023, DOI: 10.1007/s12351-023-00755-z.
- [P6] A. Labijak-Kowalska, M. Kadziński, and L. C. Dias. Robustness analysis for imprecise additive value efficiency analysis with an application to evaluation of special economic zones in Poland. 2023. Submitted to *Socio-Economic Planning Sciences*
- [P7] A. Labijak-Kowalska, M. Kadziński, and W. Mrozek. Robust additive value-based efficiency analysis with a hierarchical structure of inputs and outputs. *Applied Sciences*, 13(11), 2023

The series of scientific articles is of very high quality, as confirmed by the Impact Factor of the journals in which the articles have been published and the numerous citations of early published articles.

Journal:	Year:	IF (2 years)
Omega	2017	4,311
Energies*	2020	0,598
Expert Systems with Applications	2021	8,665
International Transactions in Operational Research	2023	3,61
Operational Research	2023	2,708
Socio-Economic Planning Sciences	Not specified (Submitted)	4,641
Applied Sciences*	2023	2,7

\*Publisher: MDPI Multidisciplinary Digital Publishing Institute

In summation, the scientific series under examination evidently attains a high standard of scientific rigor and significance, as validated by the journal Impact Factor and the copious citations it has garnered.

## **2. Wkład autora**

Anna Labijak-Kowalska introduces a novel framework for robustness analysis, which includes both mathematical programming-based methods and Monte Carlo simulation-based approaches. This framework offers a comprehensive perspective on evaluating DMU efficiency, encompassing efficiency scores, pairwise comparisons, and rankings. Additionally, the incorporation of imprecise information and hierarchical structures adds another layer of sophistication to the proposed methods. The dissertation also provides algorithms to determine efficiency reducts and constructs, further enhancing its practical utility. Moreover, the introduction of measures to aggregate outcomes for multiple scenarios is a valuable addition. The experimental comparison of existing approaches, including real-world case studies, solidifies the practical applicability of the methods proposed.

The paper, "Integrated framework for robustness analysis using ratio-based efficiency model with application to evaluation of Polish airports," authored by M. Kadziński, A. Labijak, and M. Napieraj, and published in Omega in 2017 [P1], stands out for its diverse methods for conducting robustness analysis within a ratio-based efficiency framework. These algorithms are notable for their minimal reliance on assumptions while offering a high level of discriminative power, making them well-suited for real-world applications. Moreover, the paper underscores the complementarity of results obtained through Linear Programming and Monte Carlo simulation methods. An innovative aspect of this work is the development of an open-source software tool, implemented on the diviz platform, which facilitates the practical application of the proposed framework. The practicality of the approach is exemplified through its application to the evaluation of Polish airports, considering inputs such as terminal and runway capacities, among others, and outputs related to passenger traffic and aircraft movements.

The paper titled "Quantifying electricity supply resilience of countries with robust efficiency analysis" by P. Gasser, M. Cinelli, A. Labijak, M. Spada, P. Burgherr, M. Kadziński, and B. Stojadinović, published in Energies in 2020 [P2], is of applicable value by addressing the interest in assessing the resilience of energy systems, particularly in the context of secure energy supply. To aid policymakers in evaluating their country's electricity supply resilience, the paper employs data envelopment analysis (DEA) using two models: the original ratio-based CCR model and a novel hybrid framework incorporating linear programming and Monte Carlo simulations. The study highlights limitations in

the CCR model, which fails to effectively distinguish between countries and only considers the best weight vectors for each country, potentially misrepresenting overall performance. To address these limitations, robustness analysis is utilized, resulting in the identification of more resilient countries. The paper also conducts detailed country analyses to assess their performances and potential for improvement. Overall, the research contributes valuable insights into the practical problem of assessing electricity supply resilience on a global scale, offering guidance for policymakers and energy security researchers. The article is well-written and focused on practical applications.

The paper titled "Experimental comparison of results provided by ranking methods in data envelopment analysis" by A. Labijak-Kowalska and M. Kadziński, published in *Expert Systems with Applications in 2021* [P3], conducts an extensive analysis of various ranking methods within the context of Data Envelopment Analysis (DEA). The study showcases the application of fifteen distinct approaches, representing diverse categories, including cross-efficiency, super-efficiency, multivariate statistics, decision analysis, benchmarking, virtual DMU, and social networks. Additionally, the paper introduces a new category of ranking methods based on the concept of Robustness Analysis. These methods utilize a range of feasible input/output weight vectors through Monte Carlo simulations to derive expected efficiencies, ranks, priorities, or net flow scores for Decision Making Units (DMUs). The rankings generated by all these methods are compared using both artificially generated and real-world datasets. These datasets encompass a wide range of applications, including finances, education, transportation, healthcare, farming, and the energy industry, representing the most common application areas of DEA methods. The paper employs five measures to quantify and compare the results, highlighting the significant impact of method choice on rankings. This comprehensive study contributes to the understanding of the variability in rankings and the influence of different methodologies on the recommended order or the most preferred DMU in various application domains.

The paper "Performance evaluation of emergency department physicians using robust value-based additive efficiency model" by A. Labijak-Kowalska, M. Kadziński, I. Sychała, L. C. Dias, J. Fiallos, J. Patrick, W. Michalowski, and K. Farion in *International Transactions in Operational Research* [P4] introduces a novel variant of the value-based additive data envelopment analysis model. This model conducts a comprehensive robustness analysis of efficiency outcomes for all feasible input and output weights, utilizing mathematical programming and the Monte Carlo simulation. The study also presents original procedures for selecting a common vector of weights and an approach for investigating result stability in a multiscenario setting. The proposed framework is applied to assess the performance of emergency department physicians at the Children's Hospital of Eastern Ontario in Ottawa, focusing on various patient complaint groups. The research highlights the significant impact of selected weight vectors on physician performance evaluations. It identifies strong performers who can serve as benchmarks and niche performers excelling in specific complaint groups. The results provide a

foundation for developing improvement plans for underperforming physicians, prioritizing practice-oriented models, and addressing the challenges posed by different patient complaints.

In the paper "Exact and stochastic methods for robustness analysis in the context of imprecise data envelopment analysis," authored by A. Labijak-Kowalska and M. Kadziński published in *Operational Research* [P5], the authors address the challenge of assessing the efficiency of decision-making units using a ratio-based model. The authors introduce a framework for robustness analysis that takes into account both interval and ordinal performances on inputs and outputs. Their methodology deals with the uncertainty associated with imprecise data and considers all possible input/output weight vectors within linear constraints. The paper presents methods for assessing the robustness of efficiency scores, efficiency preference relations, and efficiency ranks. To accomplish this, the authors utilize mathematical programming models to calculate extreme, necessary, and possible results. Additionally, they incorporate stochastic analysis through Monte Carlo simulations to determine the probability distribution of various outcomes. The framework is implemented in the R programming language and is available as open-source software. The paper provides practical examples of its application in two case studies involving Chinese ports and industrial robots.

The paper "Robustness analysis for imprecise additive value efficiency analysis with an application to evaluation of special economic zones in Poland," authored by A. Labijak-Kowalska, M. Kadziński, and L. C. Dias submitted to *Socio-Economic Planning Sciences* [P6], introduces a novel methodological framework based on additive value-based efficiency analysis. This approach considers inputs and outputs organized in a hierarchical structure, allowing the problem to be broken down into manageable components to assess the strengths and weaknesses of the analyzed units. The proposed method provides robust outcomes by analyzing all feasible weight vectors at different hierarchy levels, considering three complementary perspectives: distances to the efficient unit, ranks, and pairwise preference relations. For each of these perspectives, the authors determine both exact extreme results and the distribution of probabilistic outcomes. The application of this methodology is demonstrated through a case study evaluating the performance of healthcare systems in sixteen Polish voivodeships (provinces). The analysis covers the entire set of factors at the root of the hierarchy and three subcategories related to health improvement, efficient financial management, and consumer satisfaction. The paper concludes by highlighting practical insights that can be drawn from the hierarchical decomposition of the problem and robustness analysis.

The paper "Robust additive value-based efficiency analysis with a hierarchical structure of inputs and outputs," authored by A. Labijak-Kowalska, M. Kadziński, and W. Mrozek, published in *Applied Sciences* [P7], presents an innovative methodological framework centered around additive value-based efficiency analysis. This framework organizes inputs and outputs in a hierarchical structure, enabling a

systematic breakdown of complex problems into manageable components and the identification of strengths and weaknesses within the analyzed units. The methodology delivers robust results by examining all possible weight vectors at different hierarchy levels. The analysis encompasses three complementary perspectives: distances to the efficient unit, ranks, and pairwise preference relations. For each of these perspectives, the authors calculate both precise extreme outcomes and the distribution of probabilistic results. The practical application of this approach is demonstrated through a case study evaluating the performance of healthcare systems across sixteen Polish voivodeships (provinces). The analysis considers the entire set of factors at the root of the hierarchy and three subcategories related to health improvement, efficient financial management, and consumer satisfaction. The paper concludes by highlighting the valuable practical insights that can be gained from this hierarchical decomposition and robustness analysis.

The series of scientific articles is of very high quality, as confirmed by the Impact Factor of the journals in which the articles have been published and the numerous citations of early published articles. The articles are thematically related to modifications of the Data Envelopment Analysis (DEA) method. However, this collection comprises seven articles, each employing different methods, and there is a lack of emphasis on what, in the author's opinion, is the most significant outcome. While there are numerous methods associated with estimation and analysis, the descriptive part of the articles does not sufficiently underscore what the author considers the most crucial result.

### **3. Poprawność**

The correctness of the statements and justifications in the dissertation is of very good quality. The author provides a well-structured and logical presentation of the methods and their mathematical foundations. In my opinion, the presented mathematical programming models are sound, and the algorithms for sampling the space of feasible weights or scenarios are used properly and adequately adjusted to the specificity and characteristics of a particular method. The formulation of these models and algorithms required high efficiency in mathematical modeling as well as programming skills. Only under these conditions it was possible to design such a diverse family of methods. Assuming uniform distribution in the space of feasible parameters to perform the stochastic analysis is somewhat arbitrary. However, I could imagine this assumption is relaxed, and the methods can be used with any other arbitrarily assumed definition.

The thesis assigns much attention to capturing the relations between different types of robust results, including (a) the relations between exact and stochastic outcomes, (b) score-, relation-, and rank-oriented perspectives, and (c) various levels on which these outcomes can be considered. The author has also focused on discussing the evolution of results with the incremental specification of

preferences (e.g., more and more precise weight constraints). The formulated propositions and theorems are correct and practically helpful.

The descriptive part pertains to all the articles in the series. The reservation concerns the introduced notations. For example, on page 20, the full name of the Charnes, Cooper, and Rhodes (CCR) model is included for the first time, with prior usage of the abbreviation CCR. On page 21, it is initially referred to as EAII and later as The Efficiency Acceptability Interval Index.

#### **4. Wiedza kandydata**

The dissertation demonstrates a deep understanding of the existing state of knowledge in Data Envelopment Analysis. It thoroughly reviews the literature, highlighting the shortcomings of traditional DEA methods. The bibliography is comprehensive, reflecting a wide-ranging exploration of relevant sources. Including real-world case studies, such as the evaluation of Polish airports and Emergency Department physicians, further reinforces the author's expertise in applying the proposed methods.

In conclusion, Anna Labijak-Kowalska's doctoral dissertation on "New Directions in Robust Data Envelopment Analysis" significantly contributes to the field. It addresses a critical research problem, offers a novel and comprehensive framework, demonstrates correctness through rigorous methodology and experimentation, and showcases the candidate's in-depth knowledge of Data Envelopment Analysis. This dissertation advances the theoretical foundations of DEA and holds great promise for practical applications in diverse sectors, making it a valuable addition to the academic literature.

#### **5. Inne uwagi<sup>1</sup>**

Even if the scientific quality of the thesis is very high, I have two concerns that the author could address during the thesis's defense.

The thesis lacks a guide to selecting an appropriate method for a particular problem requiring efficiency analysis. The author has proposed a family of approaches which differ in their assumptions, models, and delivered results. Even if limiting the scope of consideration only to these methods, there remains an issue of which should be used to perform the analysis. Which features or questions should be taken into account in such a selection? What would be the recommended methods conditioned by the answers provided to these questions?

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<sup>1</sup> Opcjonalnie

Another issue is related to software. The developments presented in the thesis and the underlying papers were implemented in R. They had the form of web services that can be used with the *diviz* platform maintained as part of the Decision Deck project. However, it seems *diviz* will stop being maintained in the following months. Will it still be possible to use the software modules developed by the author, or, in general, what is the plan to let the users without advanced programming skills employ the proposed methods to analyze their real-world problems?

## 6. Podsumowanie

Biorąc pod uwagę opinie zaprezentowane w poprzednich punktach i wymagania zdefiniowane przez art. 187 Ustawy z dnia 20 lipca 2018 r. Prawo o szkolnictwie wyższym i nauce (z późniejszymi zmianami)<sup>2</sup> moja ocena rozprawy pod względem trzech podstawowych kryteriów jest następująca:

A. Czy rozprawa zawiera oryginalne rozwiązanie problemu naukowego? (wybierz jedną opcję stawiając znak **X**)

<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Zdecydowanie TAK	Raczej TAK	Trudno powiedzieć	Raczej NIE	Zdecydowanie NIE

B. Czy po przeczytaniu rozprawy zgadzasz się, że kandydat posiada ogólną wiedzę teoretyczną w dyscyplinie Informatyka techniczna i telekomunikacja?

<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Zdecydowanie TAK	Raczej TAK	Trudno powiedzieć	Raczej NIE	Zdecydowanie NIE

C. Czy kandydat posiada umiejętność samodzielnego prowadzenia pracy naukowej?

<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Zdecydowanie TAK	Raczej TAK	Trudno powiedzieć	Raczej NIE	Zdecydowanie NIE

Moreover, considering the thesis's high scientific level, I recommend its distinction.



Podpis

<sup>2</sup> <http://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190000276>