Recenzja spełnia wymogi formalne

Warsaw University of Technology
Faculty of Transport

Przewodniczący Rady Dyscypliny
Inżynieria Lądowa, Geodezja i Transport
Politechniki Śląskiej
prof. dr hab. inż. Piotr Folęga

Warszawa, 31.03.2025

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REVIEW

Doctoral dissertation by Artur Budzyński, M.Sc.
entitled. "Forecasting prices for road freight transport services using machine learning"

The basis for the review is Resolution No. 84/2025 of the Council of the Discipline of Civil Engineering, Geodesy and Transport of the Silesian University of Technology dated February 20, 2025 and the letter of the Chairman of the Council of Dr. Piotr Folęga, Professor of the Silesian University of Technology dated February 20, 2025 (case number RDILGT.512.32.2025).
The substantive documentation for the review is a printed copy of the dissertation by Artur Budzyński, M.Sc., entitled. "Forecasting prices for road freight transport services using machine learning" written in English, with an abstract in Polish.
The dissertation's supervisor is Prof. Aleksander Sładkowski, PhD.

1. Introduction

The submitted doctoral dissertation concerns the forecasting of prices for road freight transport services. Road freight transport constitutes one of the essential segments of the freight transport market. It is characterized, among others, by price accessibility, flexibility in adapting to the needs of specific contractors, the ability to transport cargo of various dimensions, weight, and consistency, relative speed of delivery, as well as coverage including both short and long distances, and places inaccessible, for instance, to rail or sea transport. The aforementioned characteristics make road freight transport a key element of the supply chain, ensuring the effective functioning of the entire economy.

At the same time, the transport of goods requires precise determination of the service price. This is related to the high level of competition in the transport services market and has a significant impact on the relationships between market participants. On the other hand, the final price of the transport service is influenced by numerous economic, geographical, political, weather-related, and other factors. The impact of each of these factors on the final price may be estimated based on historical data (e.g., seasonal demand); however, there are also factors whose forecasting is very difficult and requires an in-depth analysis of complex interdependencies.

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The issue of forecasting prices for freight transport services is therefore a very important element of operational planning for transport companies and other market participants associated with them. In recent years, traditional methods of price forecasting for transport services, based on statistical, empirical, or expert approaches, have been complemented by methods based on the application of machine learning techniques. This is associated, among others, with rapid technological progress, which has enabled the efficient implementation of complex algorithms using dedicated hardware (e.g., CUDA platform by NVIDIA). Moreover, the development of digital technologies (IoT, connectivity, digital maps, etc.) has made it possible to obtain a much larger amount of data than was available 10-15 years ago.

The application of machine learning techniques is not new in the transport sector. At the same time, it should be indicated that the area of forecasting prices for transport services remains an interesting direction of scientific research, primarily due to the diversity of approaches to the subject and the large number of factors influencing the result.

In this context, it should be stated that the research subject of the doctoral dissertation is current, concerns modern technologies and their application in contemporary road transport. The subject matter of the dissertation falls within the scientific discipline of Civil Engineering, Geodesy and Transport.

2. General characteristics of the dissertation

The dissertation consists of six numbered chapters written in English, accompanied by a bibliography (112 pages), a summary in English (1 page), a summary in Polish (1 page), an extended summary in English (13 pages), and an extended summary in Polish (15 pages).

The first chapter (5 pages) constitutes an introduction to the dissertation. Chapter 2 (3 pages) presents the author's research concept. In Chapter 3 (17 pages), the author outlines the theoretical foundations for the development of forecasting models and justifies the selection of specific models applied in the research. Chapter 4 (36 pages) contains a description of the methods of data collection, transformation, and analysis used by the author in the dissertation. Chapter 5 (43 pages), which is crucial from the perspective of the analysed research issue, presents the results of the calculations carried out using the method proposed by the author, as well as their interpretation. Chapter 6 (3 pages) constitutes the conclusion of the dissertation. In this chapter, the author summarizes the tasks performed and the results achieved, thus demonstrating the proper verification of the thesis of the doctoral dissertation and the achievement of its objective.

The manner in which the material is presented in the doctoral dissertation should be considered appropriate. The volume of individual chapters raises no objections. The dissertation is written in a stylistically correct language.

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The dissertation makes use of 88 bibliographic items, including scientific articles published in renowned journals such as Springer, Elsevier, MDPI, and IEEE. An essential element of the bibliography are works devoted to machine learning, transport issues, and the organization of freight transport. Furthermore, industry reports, market analyses, and legal acts have been taken into account. The majority of the cited sources originate from the last 5 to 7 years, which demonstrates the author's ability to make use of the current state of knowledge, particularly in the dynamically developing field of machine learning.

The selection of literature covers all key aspects of the dissertation: problems of road freight transport, issues related to the economic aspects of price formation for transport services, the theory of machine learning, and examples of its application in forecasting transport prices. A significant element of the literature review is the connection of the dissertation's subject matter with the European market, which allows the work to be placed in a broad international context. The inclusion of European transport data and the realities of the FTL market in the EU further strengthens the substantive value of the research. The bibliography also includes items relating to the implementation technologies of the model developed by the author—tools and libraries of the Python programming language. The selection of literature in the dissertation is closely related to the subject matter of the dissertation, substantively coherent, and interdisciplinary. It pertains both to theoretical aspects and the practical application of predictive methods.

Chapter 1 contains a brief review of scientific research in the field of freight transport services, machine learning techniques as a tool aimed at supporting the extraction of knowledge from complex transport systems, and the justification for undertaking the author's own research in the area of price prediction for transport services. At the beginning of the chapter, the author emphasizes the significance of road transport for the modern economy and logistics, identifies current trends in the development of transport services, and highlights the importance of information technologies in solving contemporary transport problems.

Subsequently, the author reviews selected areas of application of machine learning techniques in transport, including advanced analysis of large datasets, decision support in traffic systems, optimization of transport processes, road infrastructure management, and forecasting demand for transport services. The author lists types of artificial neural network models used in various fields of transport. The author emphasizes the advantages of applying machine learning methods compared to classical methods. He briefly characterizes the tools that support the process of creating IT solutions using machine learning methods, including the basic research environment of a modern scientist—Matlab, and the Python programming language as the currently leading language in the field of practical implementations of ML solutions. The author supports his conclusions with a bibliographic analysis.

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The author then focuses on the application of machine learning methods in forecasting prices for transport services. He emphasizes and justifies the significance of the issue for the transport sector, primarily from an economic perspective. He cites examples of classical approaches based on statistical data analysis. He also points out the necessity of considering many aspects in the forecasting process, including non-technical ones, based on the characteristics of transport enterprises and the relationships between process participants. The author then draws attention to the effectiveness of integrating classical econometric methods with methods based on machine learning. This is a justified and prospective approach, as it combines the functionality of proven classical models with the power of machine learning in the field of in-depth analysis of connections and non-obvious dependencies. The chapter concludes with a summary of the importance of the problem of price prediction for transport services for the entire industry.

In the reviewer's opinion, the author has correctly and unequivocally justified the scope of his research in the context of contemporary transport problems. I conclude that the doctoral dissertation presents the author's very good general theoretical knowledge in the fields of science related to freight transport and associated issues in the area of machine learning methods.

3. Substantive assessment of the dissertation

At the beginning of Chapter 2, the author, based on the analysis of the literature conducted, justifies the necessity of undertaking his own research due to the increasing complexity of the process of forecasting prices for transport services and the resulting need to apply increasingly advanced methods and IT tools. Subsequently, the author defines the research gap, consisting in the lack of a comprehensive approach to the construction of machine learning models in the segment of price forecasting for transport services in road transport. He emphasizes the necessity of developing a unified framework that would allow the management of the entire model life cycle, which would lead to predictable and repeatable results.

The author then formulates the research problem, which concerns the difficulty of forecasting prices in road freight transport due to the large number of interdependent variables and the time-consuming nature of the forecasting process. He poses a research question focused on the identification of key factors influencing the formation of prices for transport services, the development of a methodology for collecting and processing input data obtained from transport companies for the purpose of training a neural network, and the comparison of the effectiveness of the author's approach with expert assessment methods.

The author defines the primary objective of the dissertation as the development of a robust methodology for forecasting the prices of road freight transport services using machine learning techniques.

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The author then lists the tasks to be completed in order to achieve the stated objective. At the end of the chapter, the author formulates the thesis of the dissertation, in which he hypothesizes that the implementation of machine learning techniques in the forecasting of prices for road freight transport services will improve the accuracy of forecasts and enable transport companies to adjust operational decisions in response to changing conditions. He also enumerates the expected benefits of implementing such a solution in practice.

In Chapter 3, the author introduces the most important theoretical foundations for the development of forecasting models. He describes their characteristics and justifies the choice of specific models. He presents the model life cycle. He enumerates the IT tools used in the dissertation. He justifies the selection of the Python programming language for the implementation of the machine learning module. He characterizes the Python libraries used for building the models, manipulating data, and visualizing the research results. He declares the Mean Percentage Error (MPE) as the criterion for comparing the accuracy of the forecasts. He emphasizes the importance of cross-validation as one of the fundamental techniques used in machine learning for model evaluation and optimization. He discusses selected forecasting methods in machine learning, such as the historical average method, linear regression and its modifications in the form of ridge regression and regularized regression, decision trees and their modifications. He presents the advantages and disadvantages of each method, along with examples of their application areas. He describes the regression algorithms AdaBoost and XGBoost and their applicability to solving the problem of forecasting prices for transport services. He concludes the chapter with a brief discussion on the use of expert evaluation to complement and validate machine learning models.

In Chapter 4, the author focuses on the methods of collecting, transforming, and analysing the data used to build the forecasting model. At the beginning of the chapter, the author presents the method of recording input data, emphasizing the importance of their quality for obtaining the best possible forecasting results. He chooses the CSV format for the input data and justifies his choice. He then discusses the impact of the quality of the source code on the development and maintenance of the software product. He proposes the introduction of transport regionalization and the consideration of price formation specifics depending on the country. He introduces a classification of such features of the transport service as: distance, relation, date, type of cargo, type of transport, and other characteristics. He defines the recording format of each of the mentioned features.

The author then discusses the issues of preparing input data for the predictive model. He presents data transformation methods: standardization, cleaning, aggregation, and integration. Standardization of data consists in adapting them to the recording formats previously presented. Data cleaning involves the rejection of incorrect data and their replacement with a default value generated, for instance, according to a formula. Data aggregation is used to summarize trend changes over selected periods. Data integration involves the use of data from various sources and their unification into a single standardized set. The author then provides a detailed description of data transformation in the system. It

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should be emphasized that, apart from data collection, the author anticipates preliminary statistical processing of the data in the model and the placement of its results in the fields of data structures. Such an approach allows for a better interpretation of the observed dependencies. In the data processing procedure, the author indicates additional characteristics describing the loading and unloading process: mean, median, and standard deviation. Their inclusion in the model allows for a more detailed insight into the analysed processes.

At the end of Chapter 4, the author defines the categories of data that will form the basis for the analysis of the dependence of the transport service price on individual factors. This is a key element for understanding the process of forming the final price and a necessary factor in the accuracy of its forecasting. He explains the significance of correlations between the price of transport and geographical connections, seasons, fuel prices, etc. He uses external databases to supplement the model with data that would be difficult to obtain independently.

In the reviewer's opinion, the author of the doctoral dissertation correctly conducted preliminary research, identified the research gap, and formulated the objective of the dissertation. He presented a reliable and detailed plan for performing the individual steps necessary to achieve the objective:
- review and selection of forecasting models to be used in the research,
- determination of the criteria for forecasting quality,
- analysis of factors influencing the price of the transport service,
- definition of model variables and analysis of their interdependencies,
- collection and organization of source data for analysis,
- preparation of validation datasets and expert opinions for the purpose of verifying the correctness and accuracy of the model,
- classification of data and development of data formats,
- conducting the experiment, analysis, and interpretation of its results,
- verification of the working hypothesis and demonstration of the achievement of the dissertation's objective.

On this basis, I conclude that the doctoral dissertation demonstrates the author's ability to conduct independent scientific research at a high level.

In Chapter 5, the author presents the forecasting results obtained using his own method. At the beginning, he provides statistical characteristics describing the input data set. He then uses Pearson's correlation coefficient to analyse the correlation between selected numerical features of the model. He further discusses in detail the detected dependencies, illustrating them graphically with charts. He explains the nature of individual dependencies and provides his own interpretation. He indicates the asymmetry of costs in cross-border services. He shows the increase in demand for transport services in individual months of the year and the repeatability of these trends over several years. He draws attention to the

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impact of extraordinary events on the formation of transport prices. He analyses the share of different types of vehicles in transport depending on the distance between the loading and unloading points. He discusses the impact of additional costs and customs services on the final transport cost.

The author then compares the accuracy of forecasting the price of transport services for different regression models, using the same data set. He rejects models that exceeded the acceptable level of the Mean Absolute Percentage Error (MAPE) of 10%. He justifies the application of mutual validation of transport service price forecasting results through cross-validation methods and time-based splitting. He then focuses on the issue of the impact of the size of the training data set on the accuracy of price forecasting. He graphically presents the dependence of MAPE on the number of records in the training set. He shows saturation points for individual ML models.

An important element of the dissertation is the comparison made by the author of the results obtained through modelling with expert assessments. In the further part of the chapter, the author presents in detail the group of experts and characterizes them in terms of age, experience, size, and type of enterprise activity, etc. He presents the research result in the form of a validation data set, which consists of five transport offers. He uses the results of expert assessments as validation data for the forecasts obtained from the predictive models. He demonstrates the advantage of machine models over expert assessment.

The author then analyses the correlation between the price of fuel as the most significant component of the transport service price and the rate per kilometre of cargo transport. He shows that adding the GDP indicator of the country to the model does not increase the accuracy of forecasting. He also analyses the other components of the final price. He presents a summary table showing the impact of individual factors on the size of the MAPE error. He compares the training time of the model for different models and configurations of factors. Next, the author proceeds to discuss the most important features of the predictive model and the weights assigned to them. In this way, the author completes the process of presenting the characteristics of his own predictive model.

Summarizing the substantive assessment of the dissertation, it should be stated that:
-the author correctly conducted the research, developed an original method for forecasting prices of transport services, and obtained results, the correctness of which is confirmed by model validation, consistent with expert assessments and surpassing them in the accuracy of forecasts obtained on the identical input data set; this confirms the validity of the hypothesis put forward by the author at the beginning of the dissertation;
-the author correctly identified the factors influencing the pricing of the transport service and also indicated their impact on the forecast results; it should be emphasized here that only in the case of the route distance is this relationship fairly obvious—the impact of other features on the final price constitutes an original result of the author's work;

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-the model built by the author is characterized by operational speed, which allows it to be used in commercial applications, e.g., as part of a computer-based logistics system; the implementation of the model in Python significantly facilitates, in perspective, the integration of the source code;
-the author experimentally proved that the inclusion of data from external sources (fuel price databases, road fees, etc.) in the prediction model additionally increases the accuracy of forecasts;
-the predictive model developed by the author can be transferred to markets other than the European one; it can also be easily extended with additional factors influencing the final price of the transport service, which may lead to even greater forecasting accuracy; the model can also be adapted for alternative fuel sources.

In view of the above, I conclude that the submitted doctoral dissertation constitutes an original solution to the scientific problem of forecasting prices for freight transport services in road transport.

4. Comments and discussion

4.1. Substantive remarks

1) The author uses the terms "methodology" and "method" interchangeably. For instance, in section 2.3, he intends to develop an entire methodology, whereas in the results of the dissertation in Chapter 6, he indicates that a method has in fact been developed. The term "methodology" also appears in chapter headings. In the opinion of the reviewer, it is not appropriate to speak of a methodology in relation to the author's achievements. This would imply the development of an entirely new approach to solving a transport-related problem. However, the content presents an original method proposed by the author.
2) In subsection 3.2, in the first paragraph, the author writes that the chapter focuses on "the selection of appropriate machine learning techniques..."; however, in the further part, he writes about Python, libraries, the Jupyter environment, etc. Only at the end of the subsection is there a mention of the XGBoost algorithm as "an excellent choice for price forecasting...," but this conclusion is not supported by facts—neither by comparison with other algorithms nor by references to the literature. Why was only this algorithm deemed worthy of a detailed description? We will only learn about this in subsection 3.5.
3) The dissertation combines transport and IT issues. The IT part is very important for assessing the author's achievements. In the IT environment, it is customary to use graphical illustrations to describe the system structure, relationships between objects, processes occurring in the system, etc. (e.g., in the form of UML diagrams). Unfortunately, such visualizations are lacking in the dissertation. They would have been particularly useful in the description of the sources and formats of input data, their relationships, transformation algorithms, and at the modelling stage—in the form of a diagram showing what is at the input and output of the system. This would significantly facilitate the reading of the dissertation.

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4) In scientific work, it is inappropriate to use epithets such as "an ideal language for beginners," "an excellent tool," "stands out as useful," "a valuable choice for researchers," "dramatically shortened the time," etc. Such expressions are too emotional for a scientific work and are subjective. Regarding the claim that Python is an ideal language for beginners, I also have doubts. Python is a modern, fashionable programming language, well-equipped with libraries. It can be said that for experienced programmers, it is a good direction for development. However, for learning programming from scratch, it is not an ideal choice, for instance, due to its specific syntax and dynamic data types.

5) Some fragments of the dissertation could have been omitted without affecting its reception. For example, the mention of the inconsistency between Python 2 and Python 3, or the overly detailed description of the Jupyter environment.

6) The examples of the effectiveness of selected machine learning methods generally come from areas outside the field of transport; and where they do relate to the field, one may encounter, for instance, "the model achieved variance results... for attack angles of 4° and 8° respectively"; it is difficult to relate to such a result because, for a person not specialized in aerodynamics, these angles are meaningless.

7) When writing about cross-validation, the author mentions, among other things, that "it is used to evaluate model performance, optimize hyperparameters." Unfortunately, in the further part of the dissertation, I did not find a description of the hyperparameters applied in the author's model.

8) In subsection 3.5 (forecasting methods), the author presents a verbal description of algorithms and methods. I have already written above about the usefulness of graphical illustrations. I would add here that a summary table comparing the methods and algorithms, or a chart illustrating their performance, would also be helpful in this place.

9) In Chapter 4, the author refers to techniques for acquiring and processing data, known in IT as ETL (extract-transform-loading), which are widely used, for instance, in data warehouse feeding. However, this acronym does not appear in the dissertation. Moreover, the title of the chapter should more directly refer to data processing.

10) It is debatable whether the CSV format is an appropriate input data format, primarily due to the existence of many "dialects" and the lack of uniform standardization. Using this format to store data originating from various countries requires strict verification of the quality of the input data (for instance, the format of real numbers). CSV is certainly a format that is easy to handle; therefore, I do not question the author's choice. I would only like to emphasize that the programmatic implementation of the model's algorithms, especially in execution environments with various regional settings (language, dates, numbers, etc.), requires handling various formats.

11) In subsection 4.1, there is an insertion concerning the advantages of "clean code." It includes, among other things, the statement that "clean code plays a key role in effectively conducting analyses and developing predictive models." I cannot entirely agree that this is a key element of success. It is rather obvious that maintaining code in accordance with accepted principles is conducive to its development and maintenance. However, these aspects go beyond the scope of the dissertation. When listing the advantages of "clean code," the author unfortunately does not indicate what this approach would consist of in his

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dissertation—except for "it is proposed to use the English language for naming functions," which, in my opinion, in a dissertation written in English, is obvious. Therefore, I believe that this fragment could have been significantly shorter.

12) In subsection 4.3, entitled "Data Analysis Methods," the author presents not so much data analysis methods as factors influencing the formation of the price of freight transport (fuel price, distance, season, type of transport, etc.) and the relationships between them explained using correlation.

13) In Chapter 5, the author did not specify the exact origin of the data sets on the basis of which he conducted the analysis. He limits himself to the statement "using a real-world dataset." Moreover, referring to the result of the df.info() function is unnecessary and appears somewhat peculiar. The structure of a DataFrame does not depend on this function.

14) Chart 6 on page 65 starts from a distance of 0 km, for which the unit transport price exceeds 7 euros. What is the reason for this cost? How should it be interpreted?

15) In Table 28 on page 66, the total distance of routes in Poland (PL_KM) is very high compared to other countries. What is the reason for this? Was the data set analysed for logistics companies whose headquarters (or vehicle registration) is located in Poland? A similar question applies to the number of transports.

16) Chapter 5.6 is entitled "Implementation of External Databases," which may suggest that external databases will in some way be implemented by the author. However, the subsection concerns the use of data from external databases to increase the accuracy of forecasts.

17) Table 45 presents the training time for different models. As can be observed, the same data set for one of the algorithms may increase the training time, and for another—reduce it (e.g., GBoost and XGBoost, columns "basic" vs "fuel"). In the case of a different input training data set, can it be expected that the proportions in the training time for individual models will be maintained?

4.2. Editorial remarks

Page 1 (table of contents) – typographical error in section 5.4: "ferformance"
Page 29 – the phrase "despite the Polish language in the doctoral dissertation" is unclear and questionable
Page 31 – "Tab 2 presents the proposed method..." – it is a format, not a method
Page 33 – Tab. 4: "Date gathering method" – it should rather be "Date gathering format"
Page 40 – Tab. 9: typographical error in the heading of the first column: "VIHECLE" – should be "VEHICLE"
Page 40 – the VEHICLE_TYPE code includes identifiers such as "<12.5t". In Chapter 3, the quality of the code was discussed – this is not a good example of enumerator naming for vehicle type
Page 48 – the table should be moved higher so that the text "equation 7 presents" precedes the formula and not the table, as it currently appears odd
Page 48 – unused space on the page

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Page 61 – Tab. 26 could be presented in a more compact form (e.g., in two sections and with a smaller font)
Pages 61, 62, 66 – the three tables have different font sizes
Page 62 – incorrect paragraph formatting
Pages 62–67 (and further, every few pages) – too much unused space on the pages; it would be advisable to rearrange fragments of the text in such a way as to maximize the use of the page area
Page 74 – excessive use of bold font in the first column of the table
Page 86 – incomplete notation "Tab.16 ??"
Extended summary in Polish:
Page 1 – the title of the dissertation is in English
Page 9 – the chapter title is in English
Page 13 – Extended abstract – some sentences are written in Polish

5. Final conclusion

The subject of the doctoral dissertation is closely related to the scientific discipline of Civil Engineering, Geodesy and Transport. The dissertation addresses current issues related to the prediction of prices for freight transport services using machine learning techniques. The author demonstrates the ability to conduct independent scientific research. The structure of the dissertation is correct. The remarks listed in section 4 do not affect the reviewer's overall positive assessment of the dissertation.

In view of the above, I state that the doctoral dissertation of M.Sc. Eng. Artur Budzyński, entitled "Forecasting prices for road freight transport services using machine learning," meets the requirements of the Act of 20 July 2018 (as amended) – "Law on Higher Education and Science." I recommend to the Scientific Council of the Discipline of Civil Engineering, Geodesy and Transport of the Silesian University of Technology that the submitted dissertation be admitted to public defence.

Respectfully,

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