International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Optimizing for Efficiency: A Review of Grey Taguchi and RSM Based Design of Experiments Techniques for Flexible Pavements

R. Rajasekhar[1], Prasanna Sai. N[2], M. Dhilleswararao[3], S. Manikanta[4] P. Geetika[5], T. Mahesh Babu[6], R. Pravillika[7]

[1-7]Department of Civil Engineering, GMRIT, Rajam, Vizianagaram, AP, India-532127

A B S T R A C T

This paper reviews the application of Design of Experiments (DOE) methodologies, specifically Grey Taguchi and Response Surface Methodology (RSM), in optimizing flexible pavements. Traditional approaches often fail to consider interactions between variables, leading to increased costs and time. DOE enables researchers to systematically vary test variables and analyze their impact on experimental outcomes. RSM, in particular, is effective in handling multiple variables and responses efficiently. The paper contrasts Taguchi, Grey Taguchi, and RSM methodologies, highlighting their respective strengths and applications in transportation engineering. Literature on DOE applications in flexible pavements, bitumen/asphalt, and bituminous mixes is reviewed, showcasing the effectiveness of these methodologies in optimizing pavement design and performance. Practical examples demonstrate how DOE methodologies have been successfully applied to address complex engineering challenges and improve the durability, sustainability, and efficiency of flexible pavements.

Keywords: Design of Experiments (DOE), Grey Taguchi, Response Surface Methodology (RSM), Optimization, Flexible Pavements, Transportation Engineering, Bitumen/Asphalt, Pavement Design, Sustainability, Durability.

1. Introduction

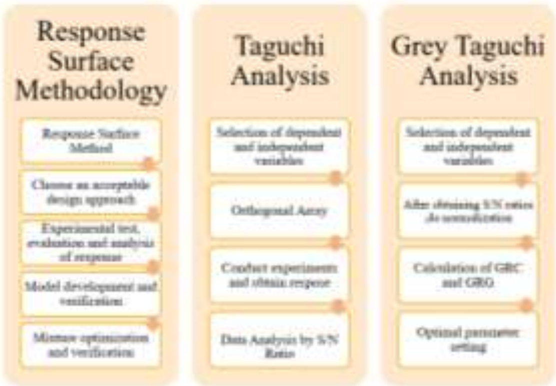
A potent technique for examining the influence of independent variables on experimental results is the Design of Experiments (DOE) method **(Montgomery, 2021)**. According to **Box et al. (2015)**, DOE enables researchers to identify correlations between variables and construct an empirical model by methodically modifying the variables and analysing their effect on a response variable. The experiment's intended outcomes can then be attained by using this model to optimise the test variables. Although process efficiency depends on optimisation, the traditional approach of examining each design parameter separately ignores the interactions between them (Montgomery, D.C., 2021). Because more testing is required, this results in higher expenses and time. One method to overcome these constraints is the Design of Experiments (DOE). DOE enables researchers to find the optimum test variable combinations and examine the effects of independent variables on experimental outcomes (Montgomery, D.C., 2021). However, to handle complicated cases (like grey-taguchi), DOE needs specific statistical models and optimisation methodologies. Response Surface Methodology (RSM) focuses on the problem of numerous response variables in engineering design and operation optimisation, even if Minitab provides a variety of DOE designs (response surface, complete factorial, etc.) and analytical tools (regression). In DOE applications, statistical modelling and optimisation methods like Response Surface Methodology (RSM) are essential **(Myers et al., 2016)**. When managing several variables and goals while taking into account different restrictions that could exist in an experiment, RSM is very helpful **(Khuri & Cornell, 2016)**. Furthermore, correlations between independent factors that affect the response are another area in which RSM shines **(Montgomery, 2021)**. Analysing residual values can help determine how well the model fits the data. Strong fits between the independent variables and the response are shown by low residual values in RSM **(Myers et al., 2016)**.

Power of RSM in Material Optimization: Trial and error and other classic material analysis techniques have their purpose, but when optimising materials with several factors, they become laborious and time-consuming **(Montgomery, D.C., 2021)**. By effectively managing several parameters at once, response surface methodology (RSM) reduces the number of tests required to solve these restrictions **(Montgomery, D.C., 2021)**. In order to create predictive models that direct the creation of new materials, it makes use of statistical design of experiments (DOE) to establish connections between processing factors and material attributes **(Antony et al., 2017; Khuri & Cornell, 2016)**. Furthermore, visualisation of the interaction between processing parameters and desired properties is made possible by RSM's ability to capture the response surface through DOE. This makes it easier to identify the best settings for achieving target material characteristics **(Aydar, 2018; Kumari & Gupta, 2019)**. While process optimization is crucial, the traditional approach of analyzing design parameters one at a time can be inefficient and overlook interactions between variables, leading to increased costs and time due to excessive testing **(Montgomery, D.C., 2021)**. This need for a more efficient method led to the development of Response Surface Methodology (RSM) by Box and Wilson in 1951 **(Montgomery, D.C., 2021)**. RSM is a statistical approach specifically designed to handle multiple response variables in engineering design and operations **(Montgomery, D.C., 2021)**.

Taguchi Technique for optimization: Inspired by Genichi Taguchi, Taguchi analysis uses Design of Experiments (DOE) and statistical techniques to optimise process and product design, but with a twist **(Freddi & Salmon, 2019)**. Taguchi emphasises robustness, or a design with less susceptibility to changes in input parameters, as opposed to traditional approaches that aim for a certain output with exact control **(Tahir et al., 2023)**. This is accomplished via a number of crucial elements. In order to quickly explore the parameter space while minimising testing, Taguchi first uses fractional factorial trials, concentrating on designs that are less vulnerable to uncontrolled variables **(Freddi & Salmon, 2019)**. Second, it gives the signal-to-noise ratio (S/N ratio), a quality indicator, first priority. S/N may be conceptualised as the ratio of a product's intended function to its undesired noise or variance **(Venkatesh et al., 2021)**. Taguchi analysis is a potent method for design optimisation that guarantees designs work effectively even with changes in input parameters by emphasising robustness and S/N ratio.

Grey-Taguchi for optimization: Owing to its shortcomings in managing multi-objective optimisation, Taguchi analysis is occasionally coupled with Grey Relational Analysis (GRA) to form a hybrid technique known as Taguchi-GRA-PCA. Principal Component Analysis (PCA), a multivariate statistical methodology that transforms correlated variables into a set of uncorrelated principal components (PCs) by orthogonal transformation, is incorporated into this method **(Kim et al., 2012)**. PCA has shown usefulness in a number of engineering design procedures. Next, in order to simplify the optimisation process, Grey Relational Analysis (GRA) plays a critical role by combining these many performance criteria into a single number.

2. Methodology



Contrast Taguchi, Grey Taguchi and RSM methodologies

3. Conclusions or results

As a result, conventional approaches to transportation engineering optimisation, such as those involving flexible pavements and asphalt mixes, were ineffective since they examined each parameter separately, neglected interactions, and necessitated a great deal of testing. One effective remedy that surfaced was Design of Experiments (DOE). Through the systematic variation of test variables and the analysis of their impact on a response variable, DOE allows researchers to identify the best combinations and investigate the effects of independent variables on experimental outcomes. Response Surface Methodology (RSM), which is perfect for complicated transportation engineering issues, also enhances DOE by managing numerous variables and responses efficiently. As a result, pavements that are more durable, sustainable, and effective may be made.

References

1. Montgomery, D.C. (2021). Design and Analysis of Experiments (10th ed.). John Wiley & Sons.

2. Box, G. E., Hunter, W. G., & Myers, R. H. (2015). An Introduction to Statistical Design of Experiments. John Wiley & Sons.

3. Myers, R. H., Montgomery, D. C., & Anderson, C. M. (2016). Response surface methodology: Process and product optimization using designed experiments (4th ed.). John Wiley & Sons.

4. Khuri, A. I., & Cornell, J. A. (2016). Response surfaces: Designs and analyses (3rd ed.). Marcel Dekker.

5. M.S.B. Pereira, "Design of flexible pavement bases using design of experiments," (2022)

6. Ramachandra et al., "Pavement preservation using system dynamics: A novel approach integrating design and maintenance decisions," (2018)

7. Jayaram et al., "A new approach for flexible pavement design using fuzzy inference system with genetic algorithm for rule base optimization," Construction and Building Materials, (2023)

8. Barbi et al., "A methodology for designing flexible airport pavements considering climatic effects," International Journal of Pavement Engineering, (2023)

9. Al Maqbali et al., "Evaluation of flexible pavement design software tools," (2021)

10. Rodrigo Siroma Shigueiro, "A Literature Review of Bitumen Ageing: From Laboratory Procedures to Field Evaluation," (2023)

11. Otávio Lima da Silva, "Analysis of the use of solid waste in road asphalt coatings: a literature review," Journal of Cleaner Production, (2023)

12. Felicia Campbell, K., "A review of the use of additives in asphalt cement," Petroleum Science and Technology, (2022)

13. Rotimi Abdulazeez, "Reuse of Waste Plastic as an Additive in Asphalt Concrete: An Overview," Journal of Materials Science and Engineering, (2022)

14. "A Literature Review of Bitumen Ageing: From Laboratory Procedures to Field Evaluation," (2022)

15. Pedro Muñoz Perez, Sócrates, "Recycled asphalt pavement in asphalt mixtures: A review," Construction and Building Materials, (2021)

16. Iranian Rocha Segundo et al., "A review on photocatalytic asphalt pavements: Materials, mechanisms, and performance," Journal of Cleaner Production, (2019)

17. Aliyu Usman, "Optimisation of asphalt mixture using response surface methodology," International Journal of Pavement Engineering, (2021)

18. Bayagoob, E., & Füleki, Á. (2022). "E-waste plastics as asphalt modifiers: A review." Waste Management, 144, 130-141

19. Ali, H., Mohammad, H., & Alabaster, D. (2024). "Laboratory evaluation of using E-waste plastics in stone matrix asphalt mixtures." Construction and Building Materials, 393, 123481.

20. Jadidi, K. (2020). "Bituminous materials in railway track design and construction: A review." Materials, 13(24), 5827.