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Predictive Multiple Regression Model for Analyzing the Impact of Gear Ratios on Electric Vehicle Performance: A Case Study of a Prototype Electric Vehicle from the Faculty of Engineering, University of Mataram

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ABSTRACT: *This study aims to develop a predictive multiple regression model to analyze the impact of gear ratios on electric vehicle performance, focusing on a case study of a prototype developed by the Faculty of Engineering, University of Mataram. The research evaluates the influence of the main gear ratios (i_1, i_2, and i_total) on output speed (n_4) and energy efficiency. Through experiments conducted on the electric vehicle prototype, it was found that gear ratios i_2 and i_total have a significant effect on reducing output speed and increasing energy efficiency. The resulting regression model provides accurate predictions of how changes in gear ratios affect vehicle performance. These findings are expected to be applied in the development of commercial electric vehicles, where optimizing gear ratios is essential to achieving a balance between energy efficiency and vehicle performance. Although this regression model offers valuable insights, the study has limitations, as other variables, such as road conditions and vehicle load, were not included in the model.*
Keywords; *Electric vehicles, Gear ratio, Multiple regression, Energy efficiency, Prototype*

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I. INTRODUCTION

Electric transportation has become one of the key solutions in the global effort to reduce dependence on fossil fuels and lower greenhouse gas emissions (Gül et al., 2024). Electric Vehicles (EVs) play a crucial role in achieving a more environmentally friendly, efficient, and sustainable transportation system (Muzalev et al., 2024; Reddy et al., 2024). With the increasing demand for energy- and cost-efficient vehicles, in-depth research on optimizing the performance of electric vehicles has become increasingly relevant, particularly regarding how the vehicle's transmission system can affect overall performance (Manoj et al., 2024; Gong et al., 2024; Jayson et al., 2024).

In the context of electric vehicles, the performance of the transmission system plays a crucial role in determining energy efficiency, acceleration, and vehicle speed. The transmission system in electric vehicles differs from that in conventional fuel-powered vehicles due to the use of an electric motor as the primary driving force. An effective transmission system enables efficient power transfer from the electric motor to the vehicle's wheels, thereby reducing energy waste and enhancing vehicle performance (Kozłowski et al., 2024). One of the key aspects of this transmission system is the gear ratio. The gear ratio refers to the relationship between the rotational speed of the motor and the rotational speed of the vehicle's wheels. In electric vehicle systems, adjusting the gear ratio can contribute to regulating vehicle speed and acceleration (Hengst et al., 2022; Spanoudakis et al., 2020b).

In electric vehicles, the gear ratio functions to either increase or decrease the power transmitted from the motor to the wheels. By adjusting the gear ratio, electric vehicles can optimize both power and energy efficiency. However, determining the ideal gear ratio for specific operating conditions remains a challenge. A gear ratio that is too low can enhance vehicle acceleration but may reduce energy efficiency. Conversely, a gear ratio that is too high can improve efficiency but at the cost of acceleration and speed. Therefore, a deep understanding of the impact of gear ratios on electric vehicle performance is crucial to achieving a balance between energy efficiency and vehicle performance (Spanoudakis et al., 2020a; Gong et al., 2024).

Previous research has shown that adjusting the gear ratio can impact the performance of electric vehicles in several aspects, such as maximum speed, acceleration, energy efficiency, and battery longevity (He et al., 2023; Ahssanet al., 2023). While numerous studies have explored how gear ratios affect the performance of conventional vehicles, research focusing on electric vehicles remains limited. This is due to fundamental differences in how electric motors operate compared to internal combustion engines (Spanoudakis et al., 2020b; Bertucci et al., 2024).

To address this, a predictive modeling approach, such as multiple regression, can be used to model the relationship between gear ratios and the performance of electric vehicles. Multiple regression enables a deeper analysis of the influence of several independent variables on a specific dependent variable—in this case, the effect of multiple gear ratios (i_1 , i_2 , and i_total) on the output speed of the electric vehicle (n_4). By using this model, we can predict how changes in gear ratios affect vehicle performance, both in terms of energy efficiency and maximum speed (Lacock et al., 2023; Elmarakbi& Morris, 2013).

This study focuses on developing a multiple regression predictive model to analyze the impact of gear ratios on the performance of electric vehicles, with a case study on an electric vehicle prototype developed by the Faculty of Engineering at the University of Mataram. This prototype is designed as part of an initiative to promote local innovation in sustainable transportation technology. The electric vehicle used in this study is equipped with a transmission system that allows for gear ratio adjustments, providing an opportunity to test how variations in gear ratios affect vehicle performance (Spanoudakis et al., 2020b; Ahmed et al., 2022).

This study aims to understand and predict how gear ratios affect the performance of electric vehicles, particularly in terms of energy efficiency, acceleration, and maximum speed. Through a multiple regression model, it seeks to identify the statistical relationship between gear ratios (i_1 , i_2 , and i_total) and electric vehicle performance (n_4 , output speed). This study is also expected to contribute to the literature on optimizing electric vehicle performance, which can be applied to the future development of commercial electric vehicles. By understanding how gear ratios influence vehicle performance, designers and engineers can develop more efficient transmission systems tailored to the operational needs of electric vehicles.

Although the multiple regression model provides valuable insights into the relationship between gear ratios and electric vehicle performance, this study has several limitations. First, the model considers only three primary gear ratios (i_1 , i_2 , and i_total) as independent variables. Other factors, such as road conditions, vehicle load, and battery condition, are not included in the model, which may influence the research findings. Additionally, this study is based on data from an electric vehicle prototype developed within the Faculty of Engineering at the University of Mataram, which may notfully represent real-world operational conditions.

II. MATERIAL AND METHODS

This study aims to develop a predictive multiple regression model to analyze the impact of gear ratios on the performance of electric vehicles. The research methodology consists of four main stages: research design, data collection, data processing and visualization, and regression modeling and analysis.

1. Research Design

This study adopts a quantitative approach with a case study design, focusing on an electric vehicle prototype developed by the Faculty of Engineering, University of Mataram. The prototype is equipped with an adjustable transmission system, allowing variations in gear ratios to be tested under controlled conditions. By utilizing this prototype, the study examines how changes in gear ratios influence vehicle performance, particularly output speed (n_4) and energy efficiency.

2. Data Collection

Data collection was conducted through direct experiments in the Electric Vehicle Research Laboratory at the Faculty of Engineering, University of Mataram. The experiment involved measuring the following key variables:i_1 is First gear ratio; i_2 isSecond gear ratio; i_totalis Total gear ratio (a combination of i_1 and i_2); n_4 – Output speed of the electric vehicle (in rpm). To ensure consistency, each dataset was collected under identical operating conditions, including vehicle load, initial speed, and battery status. The experiments were repeated with different gear ratio configurations to capture variations in performance across different settings.

3. Data Processing and Visualization

Once the experimental data was collected, it was processed using statistical visualization techniques to identify relationships between the variables. The study employed: Bar charts to compare the effect of different gear ratios on vehicle performance. Line graphs to observe trends in gear ratio adjustments and output speed. Histograms to analyze the distribution of efficiency across different gear configurations. These graphical analyses provided insights into the relationship between gear ratios, vehicle speed, and energy efficiency, helping to establish patterns in optimal gear selection.

4. Regression Modelling and Analysis

To quantify the relationship between gear ratios and vehicle performance, a multiple regression model was developed using MATLAB and EXCEL. The regression analysis aimed to predict output speed (n_4) based on variations in gear ratios (i_1, i_2, and i_total). The mathematical representation of the model is as follows:

n_4=β_0+β_1.i_1+β_2.i_2+β_3.i_total+∈⋯…………………….……………..(1)

Where n_4: Variable dependent (Output Speed), i_1, i_2, i_total: Independent variable independent (Gear Ratios), Intercept (constant), β_0, β_1, β_2, β_3: Regression coefficient region each variables independent, ∈ : Error or residual.

This model enables predictions regarding how changes in gear ratios impact output speed and energy efficiency, thereby offering valuable insights into optimizing electric vehicle transmission systems. The results of this analysis contribute to the broader understanding of gear ratio adjustments in electric vehicles and provide a foundation for further optimization in commercial EV development.

5. Determining the Regression Equation

To determine the regression equation, it is necessary to calculate the coefficients β_0, β_1, β_2, and β_3. This can be achieved using the least squares method or by employing statistical analysis tools such as MATLAB, which can automatically compute these coefficients. The multiple regression calculation for the independent variables i_1, i_2, and i_total with respect to the dependent variable n_4 is conducted using MATLAB to derive the regression equation.

6. Statistical Evaluation of the Model

Once the regression model is obtained, statistical tests are performed to evaluate its accuracy and reliability. The tests used include: R-Squared (R^2): Measures how much of the variation in n_4 can be explained by variations in i_1, i_2, and i_total. F-Test: Assesses whether the overall regression model is statistically significant. T-Test: Evaluates the significance of each independent variable in predicting n_4.

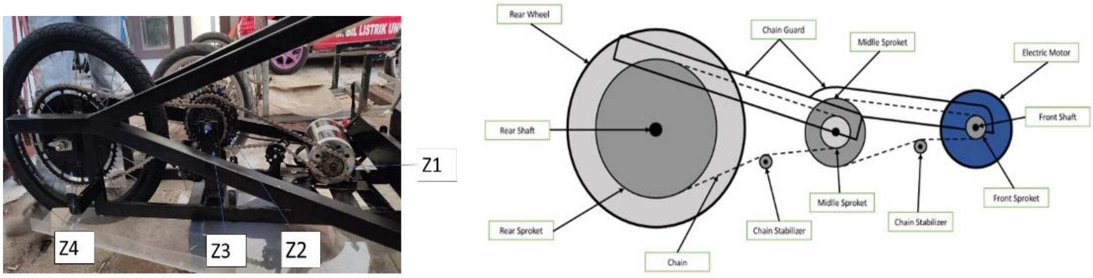
Following these statistical tests, the multiple regression results are analyzed to understand how changes in gear ratios affect output speed (n_4) and energy efficiency in electric vehicles. The independent variables with the most significant impact on n_4 are identified based on statistical significance and the magnitude of regression coefficients.

III. RESULT AND DOSCUSSION

This study utilizes a prototype vehicle, as shown in Figure 1. The vehicle is a development project by the Faculty of Engineering, University of Mataram, designed for aerodynamic efficiency and energy performance optimization. Its sleek and enclosed design indicates that the vehicle was developed with wind resistance reduction in mind, which is crucial for maintaining energy efficiency in electric vehicles.

The prototype is also equipped with a transmission system that allows for gear ratio adjustments, making it the focus of this study to examine how variations in gear ratios affect output speed and energy efficiency. This vehicle is part of an initiative to promote environmentally friendly transportation technology innovations at the local level.

Figure 1. Physical Model of the Prototype Vehicle Developed



(b)

Figure 2. (a) Physical Form and (b) Gear Ratio Modeling of the Studied Vehicle

In Figure 2(a), the developed physical model of the vehicle is shown, while Figure 2(b) represents the mathematical model of the gear system. This schematic illustrates the chain-driven drivetrain system used in the electric vehicle. The electric motor drives the front shaft, which is connected to the middle sprocket via a chain. The chain then transfers power to the rear wheel through the rear shaft and rear sprocket. Additionally, a chain stabilizer and chain guard are included to ensure the stability and safety of the system. This schematic effectively depicts the power transmission mechanism between the electric motor and the vehicle's wheels, from which data was collected for analysis.

The field measurement data is presented in Table 1. This data allows us to observe the relationship between the three primary gear ratios i_1 , i_2 , and i_total and the output speed n_4 (in rpm). The results indicate a significant influence of each gear ratio on the variation in output speed within the transmission system.

Table 1 Gear Ratios (i_1, i_2, i_{total}) and Output Speed (n_4)

No	i1	i2	i_total	n4 (rpm)
1	785714286	1666666667	130952381	2672727273
2	785714286	20	1571428571	2227272727
3	785714286	2307692308	1813186813	193030303
4	785714286	2608695652	2049689441	1707575758
5	785714286	30	2357142857	1484848485
6	785714286	3529411765	2773109244	1262121212
7	785714286	40	3142857143	1113636364
8	785714286	4615384615	3626373626	9651515152

In this dataset, the i_1 value remains relatively constant at around 0.7857 for each data point. This indicates that the i_1 gear ratio does not significantly contribute to changes in the output speed n_4 . This finding aligns with previous analyses, which suggest that variations in i_1 have minimal impact on output speed due to its small and nearly invariant value.

On the other hand, i_2 exhibits much greater variation, ranging from 1.6667 to 4.6154. An increase in i_2 is directly correlated with a decrease in output speed n_4 . For instance, when i_2 reaches its highest value of 4.6154, the output speed n_4 drops sharply to 965.15 rpm. This reflects a strong negative correlation between i_2 and n_4 , indicating that higher i_2 values significantly reduce output speed.

The total gear ratio (i_total), which combines i_1 and i_2 , follows a pattern similar to i_2 but with a sharper effect. The i_total value increases from 1.3095 to 3.6264, accompanied by a steep decline in output speed n_4 . This suggests that i_total serves as a strong predictor of output speed, where a higher i_total consistently results in a dramatic reduction in output speed.

The output speed n_4 ranges from 2,672.73 rpm to 965.15 rpm, demonstrating a significant decrease in speed as the gear ratio increases, particularly for i_2 and i_total. This trend is fully consistent with gear transmission theory, where higher gear ratios generally lead to lower output rotational speed. The relationship is illustrated in Figure 3.

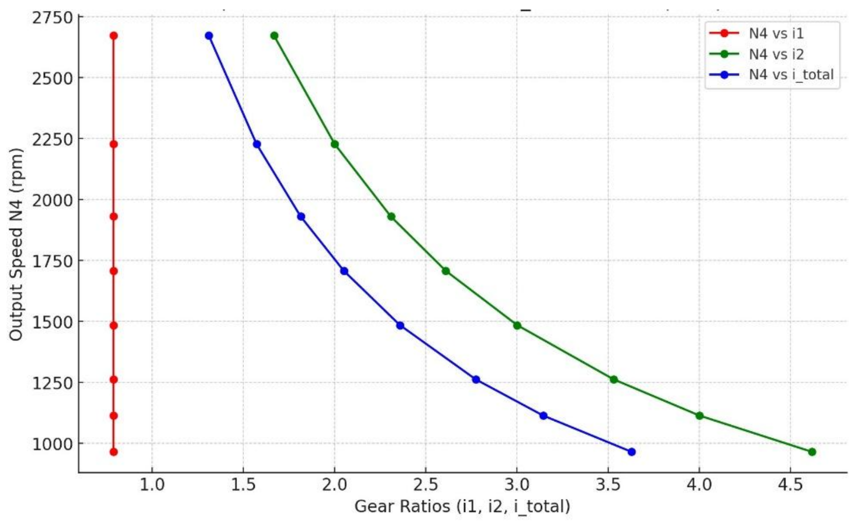


Fig. 3 Relationship Between Gear Ratios (i_1, i_2, i_total) and Output Speed (n4)

Figure 3 illustrates the close relationship between gear ratios (i_1 , i_2 , i_total) and output speed (n_4) within a transmission system. The three curves in Figure 3 provide valuable insights into how each gear ratio influences the system's output speed.

The first curve, marked in red (n_4 vs. i_1), shows that the impact of the i_1 gear ratio on output speed n_4 is negligible. This is reflected in a vertical line, indicating that changes in i_1 do not result in significant variations in output speed. This suggests that i_1 has very little or no effect on output speed an observation that aligns with the regression coefficient analysis, which approaches zero.

In contrast, the second curve, marked in green (n_4 vs. i_2), exhibits a completely different pattern. A clear decrease in output speed (n_4) is observed as i_2 increases. This curve demonstrates a strong negative relationship between i_2 and n_4 . In other words, the larger the i_2 ratio, the lower the output speed. This indicates that i_2 plays a crucial role in regulating transmission system speed, which is particularly relevant for industrial applications where precise control of output speed is essential.

The third curve, depicted in blue (n_4 vs. i_total), exhibits the sharpest downward trend. This indicates that the combination of i_1 and i_2 , represented by i_total, has a more significant impact on output speed. Overall, i_total provides a more comprehensive view of how the overall gear ratio in the transmission system influences speed.

From these three curves, we can conclude that controlling i_2 and i_total is crucial for achieving the desired output speed. While i_1 has minimal effect, i_2 and i_total play key roles in regulating the system's speed. This finding aligns with the fundamental theory of transmission systems, where an increase in the gear ratio generally results in a decrease in output speed, thereby allowing for better control over mechanical systems.

Thus, this graph offers a clear perspective on how gear ratios within a transmission system can be leveraged to effectively control output speed. For engineers, understanding this relationship is essential in designing efficient and purpose-driven transmission systems.

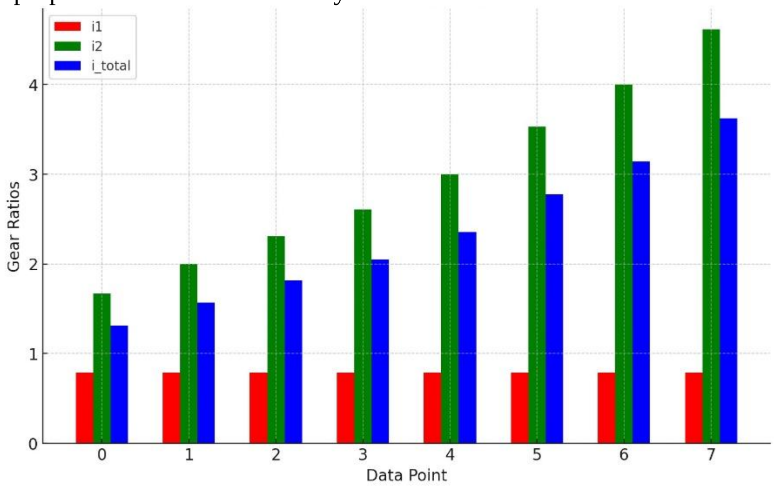


Fig. 4 Bar chart Gear Ratios (i_1, i_2, i_{total}) and Output Speed (n4)

The bar chart in Figure 4 illustrates the comparison of gear ratios (i_1 , i_2 , and i_total) at each given data point. This visualization provides insights into how these three gear ratios vary within the transmission system and influence the output speed (n_4).

The $\mathbf{i_1}$ values remain constant across all data points. This relatively small and unchanging value of i_1 indicates that its contribution to variations in the transmission system is very limited. In the context of the transmission system, this consistency confirms that i_1 is not a major factor in affecting output speed (n_4). Statistically, this suggests that i_1 has an insignificant impact on changes in output speed.

In contrast, i_2 exhibits greater variation compared to $\mathbf{i_1}$, with significant increases at different data points. The larger values of i_2 indicate that this gear ratio plays a critical role in regulating the system's output speed. Each increase in $\mathbf{i_2}$ is directly associatedwith a decrease in output speed, as expected in gear transmission theory. An increase in the gear ratio slows down the wheel rotation, ultimately reducing the output speed.

The i_total value, which is the combined result of i_1 and i_2 , follows a pattern similar to $\mathbf{i_2}$. At each data point, i_total increases, reflecting the combination of both previous gear ratios, representing the overall control of the transmission system. The increase in i_total leads to a more drastic decrease in output speed, suggesting that this variable is the primary determinant in regulating output speed (n_4).

From Table 1, a multiple regression analysis can be conducted by calculating the regression coefficients of multiple variables (i_1 , i_2 , and i_total) to predict n_4 (OutputSpeed). The steps involved in the regression analysis are as follows: Based on Equation (1), the multiple regression model obtained represents the relationship between i_1 , i_2 , i_total, and the Output Speed (n_4):

$$n_4 = 3339{,}59 + 0.i_1 - 1{,}38\text{x}10^{11}.i_2 + 1{,}76.i_{total} + \in$$

where: n_4 = Output Speed (rpm), i_1 , i_2 , i_total = Gear ratios, β_0 , β_1 , β_2 , β_3 = Regression coefficients, $\boldsymbol{\varepsilon}$ = Error term

This regression equation serves as a predictive model to quantify the impact of eachgear ratio on the output speed of the electric vehicle transmission system. The 3339.59 is the constant or intercept in the regression model. The coefficient for i_1 is 0, indicating that i_1 has no direct influence in this model. The coefficient for i_2 is -1.38×10^{11}, meaning that i_2 has a significantly negative impact on n_4 . The coefficient for i_total is -1.76×10^{11}, indicating that i_total has a strong negative effect on n_4 .

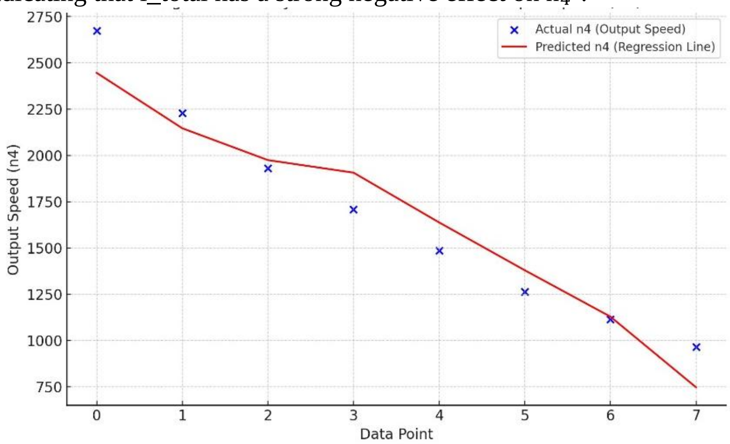


Figure 5 Regression analysis: Actual Vs Predicted output speed (n_4)

The regression graph in Figure 5 illustrates the relationship between the independent variables gear ratios (i_1 , i_2 , i_total) and the dependent variable, output speed (n_4). The graph compares the actual n_4 values (blue dots) with the predicted values obtained from the multiple regression model (red line).

From the graph, it is evident that the regression model is reasonably effective in capturing the declining trend of output speed as the gear ratios change. In general, the predictions generated by the regression model follow a similar downward pattern as the actual data, indicating that the model has a good ability to estimate $\mathbf{n_4}$ based on the gear ratio variables.

However, some discrepancies or deviations between the actual and predictedvalues can be observed. These deviations may suggest the influence of additional **factors** affecting output speed, beyond just the gear ratios. One potential factor is non-linearity, which may not be fully captured by the linear regression model. Additionally, the regression coefficients indicate that i_1 has a very minimal contribution, whereas i_2 and i_total have a greater impact on output speed. This further supports the findings that i_2 and i_total are the dominant variables in determining the performance of the electric vehicle's transmission system.

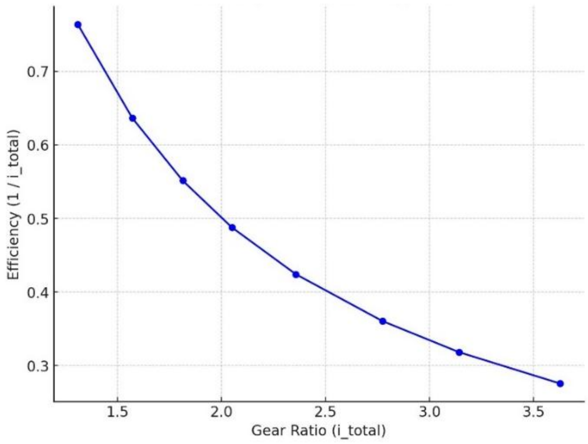


Figure 6 Efficiency vs Gear Ratio (i_{total}))

The "Efficiency vs. Gear Ratio (i_total)" graph in Figure 6 illustrates the relationship between the total gear ratio (i_total) and the efficiency of the electric vehicle system. The graph shows a significant decline in efficiency as the gear ratio increases. At lower gear ratios (around **1**.5), system efficiency reaches its peak at approximately **0.7**. However, as the gear ratio increases beyond 3.5, efficiency drops sharply, approaching **0.3**.

This phenomenon aligns with the fundamental principles of transmission systems, where higher gear ratios typically result in slower output rotation, leading to reduced wheel movement and lower energy efficiency. A higher gear ratio increases torque onthe load, but this comes at the expense of energy efficiency, as the electric motor must workharder to maintain output speed.

The decline in efficiency underscores the importance of optimizing gear ratiosettings in electric vehicle design. Engineers must balance speed and energy efficiency. While, they may also compromise long-term efficiency, impacting higher gear ratios can enhance torqueoverall performance and power consumption—especially in applications where energy efficiency is a critical priority.

IV. CONCLUSION

From the analysis of the relationship between Gear Ratios (i_1 , i_2 , i_total) and Output Speed (n_4), it can be concluded that each gear ratio plays a different role in influencing output speed. i_1 has a minimal contribution to speed variation, as evidenced by its relatively constant value across all data points. In contrast, i_2 shows significant variation and negatively affects n_4 —each increase in i_2 results in a decrease in output speed. Furthermore, i_total, which represents the combined effect of i_1 and i_2 , has the greatest impact, where an increase in i_total significantly reduces output speed. This finding highlights that i_2 and i_total are the primary factors that should be considered in transmission system design for effective speed control.

Overall, an increase in i_2 and i_total is directly correlated with a decrease in output speed (n_4), aligning with the fundamental principles of mechanical transmission systems. In industrial applications, controlling these gear ratios allows designers to adjust output speed according to specific system requirements, whether for energy efficiency or optimal performance.

It is recommended that the transmission system should focus on adjusting i_2 and i_total to achieve better control of output speed. Given that i_1 has no significant impact, its variation can be minimized in the design. Optimizing i_total is the key factor in improving system efficiency and performance. Additionally, further testing with various i_2 and i_total configurations is recommended, along with considering nonlinear models for system performance prediction. This approach will provide deeper insights and enable more precise control of output speed, tailored to specific application requirements.

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