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Development of a Calculation Model for Tank Trucks Own Use Ratio in Fuel Distribution

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Abstract

This research aims to develop a calculation model for the fuel consumption ratio in tank trucks during the fuel distribution process at one of the fuel terminals of an oil company in Indonesia. The development of this model is prompted by the obsolescence of the old ratio, which is no longer relevant to current operational needs. Fuel consumption ratio is a critical component of operational costs, making it essential to establish a more accurate and reliable model. The study adopts a full-to-full approach, measuring fuel consumption before and after distribution trips, while integrating data from the company's Online Distribution Information System (ODIS). Key variables considered in the model include tank truck type, fuel product type, route characteristics, and road gradient. Polynomial regression is employed to analyze the relationship between fuel consumption and influencing factors, ensuring a comprehensive and robust model. The analysis also incorporates the impact of road gradient on fuel consumption to enhance the model's adaptability. The findings demonstrate that the new model provides improved and reliable estimates of fuel consumption, enabling more accurate operational budget planning and reducing discrepancies in consumption data. This research contributes significantly to the development of an adaptive and dynamic fuel consumption model that enhances efficiency and supports sustainable fuel distribution operations.

Keywords
Fuel Consumption Ratio (FCR), Old Ratio, Gradient, Tank Trucks, Polynomial Regression.

Introduction
Fuel consumption efficiency is a critical component in the operational costs of fuel distribution, particularly for the Oil National Company. The company's core business processes include fuel sales, handling, fleet management, and terminal operations. One of the key terminals under the Oil National Company in the Central Java Region plays a significant role in this distribution network. This terminal covers an area of 78,180 m² and distributes various fuel products, including gasoline, diesel, high-octane fuel, and regular gasoline, to nine districts in Central Java Province. The daily distribution process involves the use of tank trucks with varying capacities (8 KL, 16 KL, and 24 KL). Accurate fuel consumption measurement is paramount given the diverse road conditions, ranging from flat to hilly terrain.

The fuel distribution process for nine districts, as illustrated in Figure 1, uses tank trucks to transport fuel to distribution institutions (gas stations and small retail outlets). The road sections traversed by tank trucks from this terminal to gas stations and retail outlets vary in condition, from flat to steep terrain. These conditions, such as narrow roads, steep slopes, or slippery surfaces (Setiawan 2021), significantly influence the arrival time accuracy at the gas station and retail outlets, underscoring the need for efficient fuel consumption.

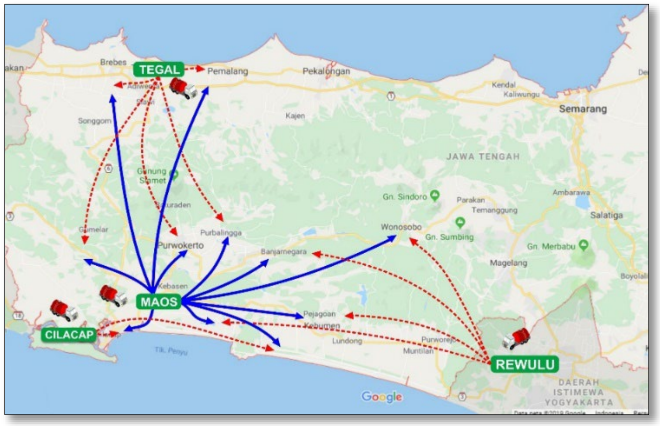

Figure 1. Distribution Area

The fuel distribution process is carried out using tank trucks with a capacity varies, namely 8 KL, 16 KL, and 24 K L. The Company has the number of tank trucks used For gas station destination 88 units as shown in Table 1.

Table 1. Tonnage of Tank Trucks

MT Data Available			Operational MT Data	
Capacity (KL)	**Units**	**Tonnage (KL)**	**Units**	**Tonnage (KL)**
8	5	40	2	16
16	32	512	24	384
24	51	1224	38	912
Total	**88**	**1776**	**64**	**1312**

Source: Internal Fleet Operations, PT Pertamina Patra Niaga (2024).

According to Study Dundar et al.(2022), increasing fuel consumption efficiency is necessary for several reasons. First, it can help reduce transportation's impact on the environment by reducing greenhouse gases and pollution. Second, it reduces fuel consumption to reduce operational transportation costs. Fuel consumption rate can be determined by measuring the amount of material fuel consumed over distance. The Fuel Consumption Ratio (FCR) in the car truck is shown in Table 2. From 2017 to the present, the calculation of fuel consumption in car tanks Still uses the ratio stated in the **Old Ratio Memo** that was created to reference the use of fuel consumption in tank trucks throughout Indonesia without notice of conditions and unique terrain in its distribution area. Therefore, there is a need to develop a new model for the fuel consumption ratio.

Table 2. Fuel Consumption Ratio **(Old Ratio Memo)**

No	Tank Trucks Capacity	Ratio
1	5 KL	5.4 KM: 1 Liter
2	8 KL	4.4 KM: 1 Liter
3	10 KL	3.8 KM: 1 Liter
4	16 KL	3.7 KM: 1 Liter
5	24 KL	3.3 KM: 1 Liter
6	32 KL	3.1 KM: 1 Liter
7	40 KL	2.7 KM: 1 Liter

Source: Internal Fleet Operations, PT Pertamina Patra Niaga (2024).

From the fuel terminal, fuel is transported to nine districts across varied terrain, as shown in Figure 2, adapted from an online topographic map (Topographic Map Online 2023).

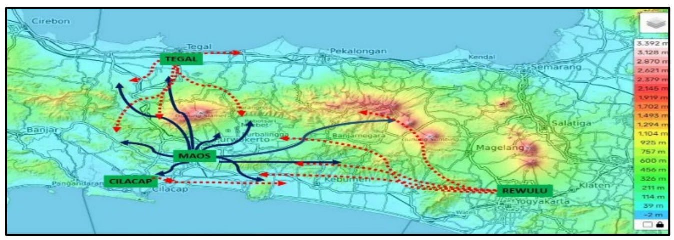

Figure 2. Road Map of Central Java Province

1.1 Objectives

The primary objective of this research is to develop a methodology capable of accurately and effectively calculating the amount of own use fuel consumption by tanker trucks during the distribution process. This research aims to delve deeper into the following specific goals, to establish a comprehensive calculation model for the own use consumption ratio (Fuel Consumption Rate), incorporating a matrix classification that encompasses critical variables in fuel distribution. These variables include the type of tanker truck used, the type of product transported, the distribution route covered, and the road gradient's topography, to evaluate and compare the proposed calculation model with the existing "**Old Ratio Memo**," ensuring that the new model is more aligned with operational contexts and delivers greater efficiency. By achieving these objectives, the research seeks to contribute to the improvement of fuel consumption calculations within the distribution operations of the energy sector.

2. Literature Review

In the transportation business, Terminal's tank trucks are classified as Class 8 trucks (Federal Highway Administration 2014), playing a crucial role in the supply chain. This function makes tank trucks not only transportation tools but also essential for sustaining various retail and industrial sectors. According to a report by Leslie et al. (2023), fuel costs are one of the largest expenses in the truck transportation industry, accounting for 52% of operational costs in 2022. These costs increased from $0.52 per mile in 2022 to $0.76 per mile in 2023. Fuel remains the primary energy source for Class 8 trucks, with fuel consumption representing 50% of operational costs (Huertas et al. 2022). High elevations or steep road geometries are not just obstacles, but they also significantly increase fuel consumption (Wood et al. 2014). Figure 3 illustrates the increased fuel consumption ratio relative to road topography for various vehicle types. This underscores the need for strategic route planning to minimize fuel consumption and operational costs.

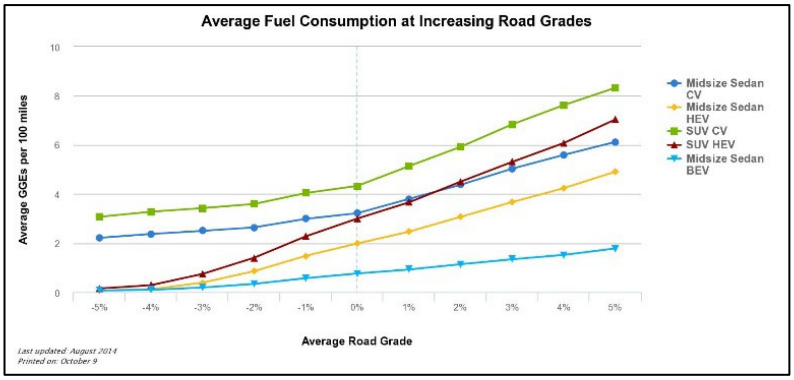

Figure 3. Chart Fuel Consumption Against Road Topography

Fuel consumption continues to increase as the road slope rises from -3% to 5% (National Renewable Energy Laboratory, 2014). Research by Hasan et al. (2022) indicates that fuel consumption increases with road elevation (gradient), with a 1% increase in road surface gradient causing a 23.75% increase in fuel consumption for dump trucks. Road topography significantly impacts energy consumption and emissions, indirectly causing longer travel distances and increased fuel consumption (Luin and Petelin 2017). Additionally, as truck loads increase, more power is required to accelerate and maintain vehicle speed, resulting in higher fuel consumption (Posada et al. 2023).

Table 3. Research with Modeling Vehicle Fuel Consumption

No	**Study**	**Truck Class**	**Modeling Approach**	**Factor Consideration in Fuel Consumption**					
				Speed	***Vehicle Age***	***Road Geometry***		***Capacity (Metric Ton)***	
						Flat	***Gradient***	***Load***	***Empty***
1	(Holzleitner et al. 2011)	Trucks Class 8	Fleet management	v	-	-	-	v	-
2	(Suzuki 2011)	Trucks Class 8	Integer Programming	v	-	-	v	v	-
3	(Xiao et al. 2012)	Trucks Class 1	Annealing Algorithm	-	-	-	-	-	-
4	(Svenson and Fjeld 2017)	Trucks Class 8	Regression Analysis	v	-	v	v	v	-
5	(Luin and Petelin 2017)	All Class	Traffic Micro Simulation	v	-	-	v	-	-
6	(du Plessis et al. 2023)	Trucks Class 8	Regression Multiple	-	-	-	v	v	-
7	(Small and Ghaffariyan N 2023)	Trucks Class 8	Regression Analysis	-	-	-	v	v	-
8	(Anttila et al. 2022)	Trucks Class 8	Regression Analysis	v	-	-	v	v	-
9	(Cvitanić et al. 2023)	Trucks Class 8	Regression Analysis	v	-	-	v	-	-
10	(Mumcuoglu and Farea 2023)	Trucks Class 8	Machine Learning Techniques	-	-	-	v	-	-

11	(Zhou et al. 2017)	Trucks Class 8	Dynamic Programming	v	-	-	v	-	-
12	(Wang and Rakha 2017)	All Class	Regression Analysis	v	-	-	v	v	-
13	**This Research (2023)**	**Trucks Class 8**	**Regression Polynomial + Fleet Tool**	**v**	**v**	**v**	**v**	**v**	**v**

Table 3 compares various studies on vehicle fuel consumption modeling approaches and the factors considered. Unlike previous studies, which primarily rely on regression analysis or other techniques such as integer programming and machine learning, this research (2023) uniquely combines polynomial regression with a fleet tool. Additionally, it comprehensively incorporates multiple critical factors—speed, road gradient, road geometry, load, age and empty conditions—providing a more holistic approach compared to the narrower focus of earlier studies. This model uses engineering and simulation techniques to optimize fuel consumption for various operating conditions, providing more accurate and reliable fuel consumption estimates. This study's novelty lies in its ability to adjust parameters based on vehicle characteristics and fuel distribution routes. This research contributes to the development of sophisticated and effective own-use ratio calculation models, enhancing efficiency and sustainability in the transportation business. It also offers valuable insights for future research.

3. Methods

The methodology for this research is structured into four main components to ensure comprehensive results
Step 1: Data Collection, Primary and secondary data were collected from various sources, including truck specifications, fuel consumption records, road slope profiles, and route information. Data collection involved both manual measurements and automated systems to ensure accuracy and comprehensiveness.

Step 2: Data Processing, The collected data were cleansed, integrated, and transformed to ensure readiness for analysis. This involved removing outliers, filling missing values, and normalizing data. Data processing also included categorizing routes based on their characteristics and identifying patterns in fuel consumption.

Step 3: Model Development, Polynomial regression models were used to capture the relationships between speed, road gradient, and fuel consumption. Additional features such as squared terms and interaction terms were included to account for non-linear effects. The model development process involved selecting the best-fit polynomial degree and optimizing the model parameters. evaluate the model. Cross-validation techniques were employed to assess the model's robustness and prevent overfitting, An experimental matrix was created to test different combinations of truck loads, ages, speeds, and road gradients. This matrix included a wide range of scenarios to ensure the model's generalizability. The experiments were conducted under controlled conditions to isolate the effects of each variable.

Step 4: Model Verification and Validation, The developed model was verified and validated using a separate dataset to ensure its accuracy and reliability. Performance metrics such as Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R-squared (R^2) were used to evaluate the model. Cross-validation techniques were employed to assess the model's robustness and prevent overfitting

In this research , the stages it goes through is designed for answering question as shown in Figure 4.

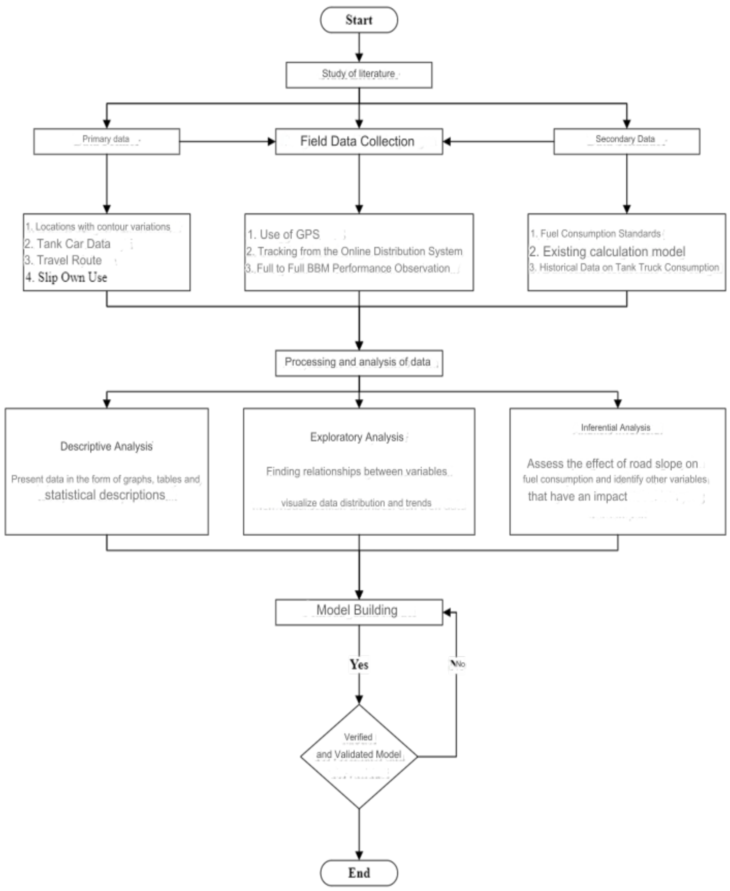

Figure 4. Research Flowchart

3.1 Road Survey

The comprehensive process involved in conducting a road survey for fuel consumption analysis. This survey is critical for gathering accurate data on fuel usage, ensuring the reliability and efficiency of our fuel consumption ratio (FCR) model. Here is a step-by-step overview of the process:

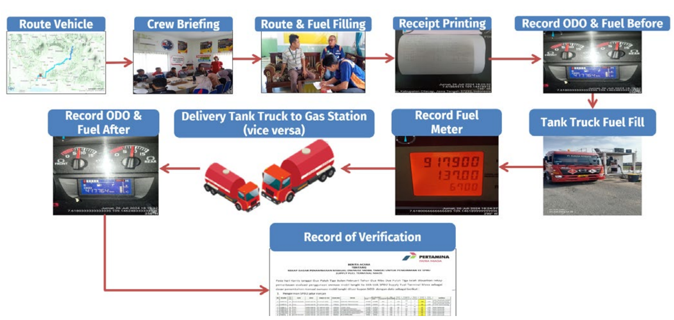

Figure 5. Road Survey

The road survey process (Figure 5) is crucial for gathering accurate data on fuel consumption, which is essential for validating our fuel consumption ratio (FCR) model. The survey begins with selecting and mapping the vehicle's route, followed by a detailed briefing with the crew to ensure they understand the procedures and objectives. Initial fuel filling is meticulously documented, and odometer readings and fuel levels are recorded before starting the journey. This provides precise baseline data for calculating distance traveled and fuel consumed.

During the journey, the tank truck delivers fuel to various gas stations along the predetermined route. At each stop, fuel meter readings are recorded to track the amount of fuel dispensed. This systematic and methodical approach ensures consistent data collection across different locations and conditions. Final odometer readings and fuel levels are recorded at the end of the journey, providing the necessary data to compute the total distance traveled and fuel consumed.

The collected data is then cross-checked with printed receipts and meter readings to ensure accuracy. A verification report summarises the findings and confirms the data's validity. This thorough process of data collection and verification is crucial for developing an accurate FCR model, which will help optimize fuel distribution, reduce operational costs, and improve overall efficiency in fuel logistics operations.

Our comprehensive road survey results offer critical insights into fuel consumption patterns across various routes. This survey monitored 17 tank trucks (Table 4), each with specific routes, capacities, and fuel consumption records. The following section details these findings.

Table 4. Road Survey Results

No	License Number	Capacity	Gas Station	City	Distance		FCR (Liter)	
					One Way	Two Way	Original	Additional
1	E9456YB	16	4452317	Kab Pemalang	80	160	48	3
2	E9260YB	8	4452317	Kab Pemalang	80	160	40	3
3	B9290TFV	16	4452423	Kab Tegal	109	218	66	37
4	E9391YB	8	4452423	Kab Tegal	109	218	55	37
5	E9334YC	16	4453404	Kab Banjarnegara	144	288	87	12
6	AA8410OP	8	4453404	Kab Banjarnegara	144	288	72	12
7	E9389YB	16	4453406	Kab Banjarnegara	115	230	70	2
8	H 9677 OF	8	4453406	Kab Banjarnegara	115	230	58	2
9	E9390YB	24	4456211	Kab Temanggung	139	278	84	9
10	N9865UJ	16	4456211	Kab Temanggung	139	278	84	1
11	G9214OA	24	4456309	Kab Wonosobo	133	266	81	5
12	G8107OA	24	4456310	Kab Wonosobo	131	262	79	16
13	G8106OA	24	4456312	Kab Wonosobo	116	232	70	17
14	R9029B	16	4456312	Kab Wonosobo	116	232	70	6
15	E9260YB	16	4553411	Kab Banjarnegara	128	256	78	5
16	R9564B	8	4553411	Kab Banjarnegara	128	256	64	5
17	E9446YB	16	4553413	Kab Banjarnegara	133	266	81	23

The survey covers tank trucks with varying capacities, ranging from 8 to 24 kiloliters (KL). These trucks operated on routes to different gas stations in multiple cities, The routes taken by each truck were carefully selected to represent typical distribution paths. Distances varied significantly, with one-way trips ranging from 80 to 144 kilometers and two-way trips ranging from 160 to 288 kilometers. This variation in distance helps to understand how different travel lengths impact fuel consumption.

Fuel consumption data was recorded in two categories: original consumption and additional consumption. Original consumption represents the standard fuel usage for completing the route, while additional consumption accounts for extra fuel used, possibly due to factors like traffic conditions, road gradient, and load weight. For instance, the truck with license number E9456YB, with a capacity of 16 KL, traveled a two-way distance of 160 kilometers to Pemalang and recorded an original fuel consumption of 48 liters with an additional 3 liters. Similarly, the truck with a capacity of 16 KL, traveled a two-way distance of 218 kilometers to Tegal and recorded an original fuel consumption of 66 liters with an additional 37 liters. These figures highlight the significant impact of route-specific factors on fuel consumption.

The data reveals several critical insights. Trucks with higher capacities, such as the 24 KL trucks, generally consumed more fuel due to the increased load. However, the additional consumption varied significantly, indicating the influence of route-specific factors like road conditions and traffic patterns.

The survey results are instrumental in identifying opportunities for optimizing fuel consumption. By analyzing the data, we can pinpoint routes and conditions that lead to higher fuel usage and develop strategies to mitigate these factors. For instance, improving route planning to avoid high-traffic areas or steep gradients can reduce additional fuel consumption. Moreover, understanding the fuel consumption patterns allows for better budget planning and resource allocation. Accurate predictions of fuel needs based on empirical data ensure that the distribution network operates efficiently, reducing operational costs and enhancing sustainability. These results are not just informative, but they are crucial for making informed decisions and improving the efficiency of our operations.

3.2 Experimental Design to Generate FCR Figures

The detailed experimental design framework used to generate the Fuel Consumption Rate (FCR) figures is crucial for developing a robust and accurate model. This framework comprises three critical steps: Identification of Experimental Variables, Experimental Matrix Design, and Data Analysis.

Independent Variables:

1. Truck Load: consider three different truck loads for this experiment: 8 tons, 16 tons, and 24 tons. These variations in load help us understand how weight affects fuel consumption.
2. Speed: The speed of the truck is varied in increments of 10 km/h, ranging from 10 km/h to 60 km/h. This range allows us to analyze how changes in speed impact fuel efficiency.
3. Gradient: Road gradient is another crucial variable, with values ranging from 0% (completely flat) to 10% in increments of 1%. This gradient variation helps us study the effect of road steepness on fuel consumption.

Dependent Variable:

The primary dependent variable in our study is the Fuel Consumption Rate (FCR), measured in kilometers per liter (km/L). This metric indicates the efficiency of the truck in utilizing fuel over different conditions.

B. Experimental Matrix Design:

The next step involves designing the experimental matrix. This matrix is a comprehensive combination of all the independent variables: truck load, speed, and gradient. By creating a matrix that includes every possible combination of these variables, we ensure that our analysis covers a wide range of scenarios. This thorough approach allows us to capture the interactions between variables and their collective impact on FCR.

A. Identification of Experimental Variables:

The first step in our experimental design involves identifying both the independent and dependent variables that will influence the Fuel Consumption Rate (FCR).

4. Data Collection

The final step is the data analysis phase, where the collected data from the experimental matrix is analyzed to establish relationships between the independent and dependent variables. We employ a polynomial regression model for this analysis. Polynomial regression is particularly useful for modeling the non-linear relationships between the variables, providing a more accurate representation of real-world scenarios. Polynomial regression model allows us to create a functional relationship between the FCR and the independent variables. By fitting the data to a polynomial curve, we can identify the coefficients that best explain the variations in fuel consumption. This analysis not only helps in understanding the direct effects of each variable but also their interactions. This experimental design is meticulously crafted to cover all relevant variables that impact fuel consumption. Polynomial regression models the relationship between the independent variable x and the dependent variable y as degree polynomial (Hastie, Tibshirani, and Friedman 2009). The model can be written as. This model will be instrumental in optimizing fuel consumption, reducing costs, and improving the overall efficiency of fuel distribution operations. The general of a polynomial regression model is:

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + \cdots + \beta_n x^n + € \qquad (1)$$

Where:

y is the dependent variable
x is the independent variable
β_0 is the intercept.
$\beta 1, \beta 2, \ldots, \beta n$ are the coefficients for the independent variables and their higher-order terms.
ϵ is the error term.

For calculating the Fuel Consumption Rate (FCR), we consider multiple independent variables: Speed, Load, Ages and Gradient. The polynomial regression model for FCR can be expanded to include these variables and their interactions:

$$\boldsymbol{Fuel\ Consumption\ Rate} = 5.6026 - 0.1516.M + 0.1249.A - 0.0064.S - 0.1459.G - 0.0443.L + 0.0026.M^2 + 0.0003.M.A - 1.3691e^{-05}.M.S - 0.00040553.M.G - 0.0121538.M.L + 0.2709817.A^2 + 0.00080768.A.S + 0.0032315.A.G + 0.0057985.A.L - 1.4299e^{-05}.S^2 - 3.6105e^{-05}.S.G + 9.8945e^{-05}.S.L + 0.00074758.G^2 + 0.0024585.G.L + 0.03440742.L^2 \quad \textbf{(2)}$$

Where:
M = Mass (Load) of the vehicle (ton)
A = Age of the vehicle (years)
S = Speed of the vehicle (km/h)
G = Gradient of the road (%)
L = Load (additional weight) of the vehicle (ton)

The polynomial regression model above illustrates the relationship between the Fuel Consumption Rate (FCR) and multiple independent variables, including speed (S), load (L), vehicle age (A), and road gradient (G). By incorporating higher-order terms and interaction effects, this model provides a more precise representation of how these factors collectively influence fuel consumption. The expanded form of the equation highlights the complexity of the interactions between variables, emphasizing the importance of accounting for non-linear effects in analyzing and optimizing fuel efficiency.

5. Results and Discussion

5.1 FCR Interpolation Matrix

FCR Interpolation Matrix provides a detailed and nuanced understanding of how speed, age, gradient, and truckload interact to influence fuel consumption. By analyzing the data presented in the matrix, we can make informed decisions to enhance fuel efficiency, reduce operational costs, and improve the overall sustainability of logistics operations. This detailed interpretation highlights the practical applications of the matrix in real-world scenarios, underscoring its value as a tool for fuel management and route optimization. Below Table 5, an interpretation section explains the key trends and comparisons observed from the data.

Table 5. FCR Interpolation Matrix

Variables		Gradient (%)	0		1		2		3		4		5		6		7	
		Load Condition	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded
Truck Capacity (Ton)	Vehicle Age	Speed (km/h)																
8	0-5 Years	10	4,40	4,46	4,27	4,36	4,11	4,12	3,97	4,12	3,83	4,00	3,57	3,68	3,52	3,49	3,46	3,55
		20	4,34	4,40	4,20	4,29	4,09	4,09	3,98	4,07	3,89	3,89	3,54	3,58	3,73	3,51	3,17	3,54
		30	4,26	4,35	4,15	4,23	4,02	4,02	3,88	3,84	3,79	3,67	3,75	3,70	3,28	3,65	3,47	3,17
		40	4,24	4,27	4,08	4,15	3,90	4,03	3,94	3,81	3,79	3,68	3,52	3,55	3,30	3,45	3,15	3,51
	5-10 Years	10	4,40	4,46	4,28	4,30	4,13	4,21	3,99	3,99	3,78	3,92	3,69	3,90	3,40	3,57	3,70	3,55
		20	4,34	4,39	4,24	4,26	4,07	4,05	3,87	3,91	3,74	3,77	3,52	3,79	3,69	3,61	3,49	3,57
		30	4,26	4,35	4,13	4,17	4,00	4,00	3,95	4,03	3,64	3,74	3,49	3,73	3,40	3,63	3,52	3,59
		40	4,22	4,29	4,09	4,11	3,92	4,06	3,75	3,87	3,65	3,76	3,72	3,64	3,43	3,50	3,41	3,23
	10-15 Years	10	4,10	4,18	3,95	4,04	3,78	3,83	3,71	3,84	3,47	3,76	3,55	3,55	3,30	3,39	3,36	3,43
		20	4,05	4,11	3,92	3,98	3,85	3,81	3,61	3,74	3,52	3,46	3,29	3,57	3,03	3,20	3,29	2,98
		30	4,01	4,06	3,88	3,94	3,79	3,86	3,59	3,62	3,58	3,44	3,37	3,33	3,14	3,23	3,02	3,20
		40	3,92	4,00	3,81	3,88	3,66	3,65	3,46	3,46	3,33	3,50	3,19	3,46	3,01	2,96	2,83	3,03
16	0-5 Years	10	3,70	3,76	3,59	3,59	3,38	3,53	3,33	3,24	3,13	3,26	3,10	2,92	2,99	2,91	2,52	3,00
		20	3,64	3,70	3,49	3,58	3,43	3,39	3,14	3,31	2,97	3,21	3,08	3,11	2,95	2,97	2,62	2,59
		30	3,58	3,63	3,46	3,51	3,31	3,31	3,10	3,27	3,01	3,01	2,79	3,01	2,87	2,76	2,79	2,52
		40	3,51	3,55	3,37	3,39	3,32	3,30	3,09	3,07	3,05	3,14	2,71	2,93	2,84	2,78	2,34	2,82
	5-10 Years	10	3,70	3,76	3,57	3,60	3,41	3,53	3,30	3,27	3,17	3,32	2,86	3,07	2,82	3,03	2,55	2,77
		20	3,65	3,70	3,53	3,55	3,43	3,41	3,34	3,18	3,16	3,11	2,83	3,03	2,70	2,88	2,58	2,63
		30	3,58	3,64	3,46	3,50	3,30	3,40	3,18	3,29	3,08	3,19	2,88	2,92	2,78	2,85	2,41	2,67
		40	3,52	3,59	3,39	3,43	3,30	3,35	3,06	3,09	2,83	3,13	2,79	2,84	2,51	2,72	2,44	2,61
	10-15 Years	10	3,42	3,49	3,27	3,33	3,13	3,19	3,06	3,07	3,02	3,07	2,67	2,82	2,71	2,60	2,49	2,71
		20	3,33	3,43	3,24	3,27	3,03	3,19	2,91	3,00	2,70	2,87	2,72	2,89	2,50	2,77	2,65	2,48
		30	3,32	3,37	3,16	3,22	3,07	3,03	2,90	3,03	2,66	2,69	2,64	2,74	2,60	2,53	2,49	2,26
		40	3,23	3,33	3,10	3,09	2,90	3,05	2,84	2,88	2,81	2,78	2,74	2,58	2,54	2,55	2,17	2,49
24	0-5 Years	10	3,30	3,35	3,19	3,25	3,03	3,01	2,81	2,97	2,70	2,87	2,68	2,72	2,35	2,50	2,34	2,46
		20	3,24	3,30	3,14	3,18	2,90	3,07	2,93	2,80	2,66	2,71	2,57	2,57	2,26	2,52	2,50	2,29
		30	3,19	3,25	3,06	3,09	2,92	3,00	2,69	2,86	2,64	2,64	2,64	2,57	2,57	2,46	2,33	2,46
		40	3,13	3,18	3,02	3,02	2,87	2,89	2,77	2,72	2,58	2,64	2,54	2,63	2,46	2,34	2,01	2,27
	5-10 Tahun	10	3,30	3,35	3,18	3,25	2,99	3,03	2,82	2,84	2,78	2,89	2,66	2,60	2,46	2,52	2,46	2,46
		20	3,24	3,29	3,12	3,17	2,97	3,00	2,80	2,83	2,76	2,69	2,66	2,72	2,23	2,58	2,49	2,41
		30	3,20	3,25	3,05	3,14	2,92	2,96	2,66	2,79	2,73	2,64	2,32	2,40	2,49	2,41	2,35	2,51
		40	3,15	3,15	2,96	3,09	2,84	2,84	2,79	2,86	2,52	2,61	2,57	2,50	2,44	2,23	2,07	2,43
	10-15 Years	10	3,03	3,08	2,88	2,93	2,70	2,84	2,64	2,75	2,47	2,66	2,15	2,52	2,04	2,23	2,22	1,96
		20	2,95	3,01	2,85	2,85	2,73	2,79	2,60	2,49	2,33	2,35	2,11	2,40	2,28	2,38	2,08	2,17
		30	2,89	2,94	2,74	2,85	2,72	2,72	2,43	2,44	2,41	2,38	2,29	2,34	2,13	2,31	1,82	2,26
		40	2,80	2,89	2,69	2,76	2,55	2,58	2,50	2,39	2,34	2,27	2,08	2,19	2,05	2,13	2,02	1,90

5.2 Graphical Results

This analysis will present a series of graphical visualizations aimed at providing a comprehensive understanding of the relationships between various variables influencing the Fuel Consumption Rate (FCR) of tanker trucks with different capacities. The visualizations include 2D (two-dimensional) integrating variables such as road gradient, speed, vehicle age, and load conditions (loaded/unloaded) for each tanker truck capacity, namely 8, 16, and 24 tons.

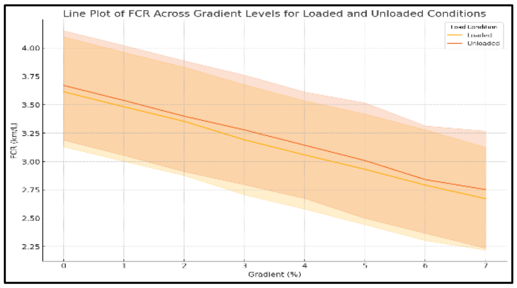

Figure 6. Graph FCR Across Gradient Levels for Load Condition

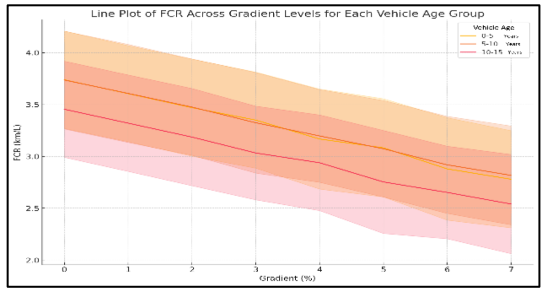

Figure 7. Graph FCR Across Gradient Levels for Each Vehicle Age Group

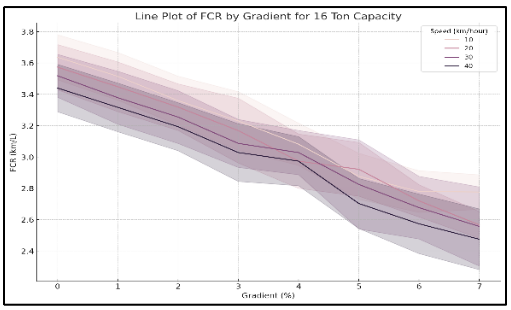

Figure 8. Graph of FCR by Gradient for 16 Ton Capacity

Figure 6 demonstrates that as vehicle load increases, fuel consumption also rises, resulting in a decrease in FCR (km/L). Loaded vehicles consistently show higher fuel consumption compared to unloaded ones, with the impact of load diminishing on steeper gradients due to gravitational effects. This emphasizes the importance of managing load distribution to optimize fuel efficiency.

Figure 7 highlights the relationship between vehicle age and fuel consumption, showing that older vehicles consume more fuel, leading to a lower FCR. This trend is most apparent on flatter gradients, where newer vehicles benefit from advanced technologies and better engine performance. On steeper slopes, the differences between age groups are less pronounced as gradient effects dominate fuel efficiency.

Figure 8 reveals that as vehicle speed increases, fuel consumption also rises, causing a reduction in FCR. Higher speeds are more fuel-efficient on shallow gradients due to optimized engine performance, but on steeper gradients, the differences in FCR across speed levels narrow as gravitational forces take precedence. This underscores the need for careful speed management to balance fuel efficiency and operational demands.

Overall, there is a noticeable trend of increasing FCR as the road gradient rises, indicating that fuel consumption per kilometer tends to be higher on steeper roads. Additionally, vehicles in an unloaded condition exhibit a higher FCR compared to fully loaded vehicles across all capacities, highlighting the significant impact of load on fuel efficiency. The influence of vehicle age is also apparent, with older vehicles tending to have a higher FCR compared to newer ones, further demonstrating the role of vehicle condition in fuel efficiency.

5.3 Verification Models

After the model is developed, the next step is to perform validation and verification to ensure that the model accurately reflects real-world conditions:

a) Model Goodness of Fit Test: Use data that was not included in the initial calculations to validate the fuel consumption predictions (Figure 9).

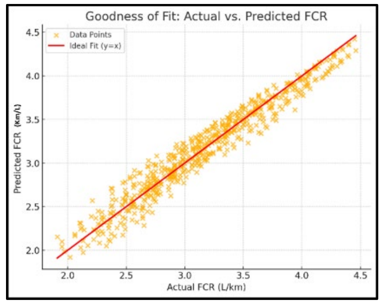

Figure 9. Goodness of Fit

The graph illustrates the relationship between actual and predicted values, with the red line serving as the ideal reference (y = x). Most data points align with this line, indicating reasonably accurate predictions.

b) Residual Analysis: Perform a residual analysis to ensure that the fuel consumption predictions do not exhibit systematic bias (Figure 10)

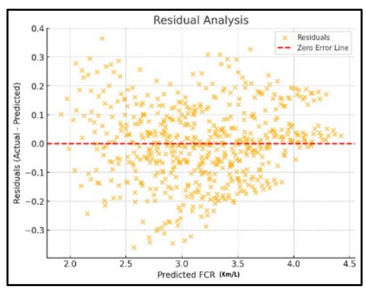

Figure 10. Residual Analysis

The residual plot shows a uniform distribution around the zero line, indicating that the model does not exhibit systematic bias in its predictions.

5.4 Validation Models

Table presents a comparison between the actual data and the model's predictions for fuel consumption (FCR) and Own Use. The validation results (Table 6 and Table 7), evaluated using metrics such as MAE, MSE, RMSE, and R^2, indicate that the model demonstrates excellent accuracy in predicting fuel consumption and Own Use values. With an R^2 value close to 1, the model effectively represents the relationships between variables and provides predictions that are consistent with the actual data.

Table 6. Comparison of Real Model FCR and Own Use

VALIDATION				REAL				MODEL		
Capacity	Distance	Route		Ownuse (Litre)				Ownuse (Litre)		
		Trip	Gradient	Origin	Add	FCR	Total	FCR (Go)	FCR (Return)	Interpolation
16	160	Pemalang	2,00%	42	5	3,40	47,00	3,43	3,41	46,78
8	160	Pemalang	3,00%	40	3	3,72	43,00	3,61	3,74	43,55
16	218	Tegal	5,00%	43	32	2,91	75,00	3,01	2,87	74,19
24	262	Wonosobo	3,00%	78	18	2,74	95,69	2,66	2,79	96,20

Table 6 compares real and modeled fuel consumption rates (FCR) and own use (fuel usage) across different vehicle capacities, distances, gradients, and routes. The table provides details on real fuel usage data, including origin fuel consumption and additional usage, as well as the modeled FCR values for both outbound (Go) and return trips. Interpolation results are also included to estimate total fuel usage under varying conditions. The comparison highlights minimal differences between real and modeled FCR values, demonstrating the model's accuracy in predicting fuel consumption across diverse gradients and operational routes. This table validates the practical applicability of the model in real-world scenarios, addressing the need for reliable predictions of fuel consumption to improve operational efficiency.

Table 7. Verification Validation FCR andOwnuse

Verification & Validation	FCR	Total Ownuse (Litre)
MAE (Mean Absolute Error)	0,08	0,52
MSE (Mean Squared Error)	0,01	0,32
RMSE (Root Mean Squared Error)	0,09	0,56
R^2 (R-squared)	0,95	0,99

Table 7 presents the statistical validation metrics used to assess the model's performance, including Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R^2 values. These metrics are calculated for both the FCR and total own use (liters), showing low error values (e.g., MAE of 0.52 for own use) and high R^2 values (0.95 for FCR and 0.99 for total own use). The results indicate a strong correlation between the modeled and real data, confirming the model's accuracy and robustness. This table provides statistical evidence supporting the reliability of the model in accurately predicting fuel consumption, thus addressing the research problem of optimizing fuel usage estimation.

6. Conclusion

This study successfully developed a fuel consumption ratio (own use ratio) model for tanker trucks operating in fuel distribution at Terminal in Oil National Company, providing better and more efficient predictions compared to previous models. The key factors influencing the Fuel Consumption Rate (FCR) include road gradient, where higher gradients increase fuel consumption due to higher power requirements; vehicle speed, which shows a non-linear relationship with FCR, being higher at speeds below 20 km/h and above 40 km/h; load condition, with unloaded vehicles consuming more fuel than loaded ones; vehicle age, where older vehicles exhibit higher FCR on low to moderate gradients; and vehicle capacity, with larger capacities being more efficient at optimal speeds and gradients. The polynomial regression model accurately captured the non-linear relationships between variables and their interactions, such as gradient and load capacity, outperforming simple linear regression. With an R^2 value of 0.95 for FCR and 0.9993 for Own Use, the model explains most of the variability in actual data, and low error metrics (MAE: 0.08 for FCR and 0.52 liters for Own Use; RMSE: 0.09 for FCR and 0.56 liters for Own Use) confirm its accuracy. For further development, incorporating additional factors like weather variations and driver behavior, testing under diverse operational conditions, and comparing with other models in different transportation sectors are recommended to enhance accuracy and applicability.

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