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Research Paper

Presentation of a Multiple Regression Model to Determine the Distance of Primary Arterial Roads and Building Density in a Radial-Circular Network

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Abstract

The form of urban networks plays a crucial role in the efficiency of traffic flow. Small deficiencies in the geometric design or spatial distribution of arterial networks can disrupt traffic continuity, reduce operational efficiency, and lead to increased congestion in urban transportation systems. The distance between roads with different functions is one of the most significant parameters affecting traffic in urban networks. Therefore, in this study, a radial-circular network was designed with primary arterial roads at varying distances (800 and 1200 meters) and building densities ranging from 100% to 250%. Using AIMSUN software, the network was simulated, and traffic parameters were extracted. Subsequently, a predictive model was developed using multiple regression analysis, with primary arterial road distance as the dependent variable and building density and traffic parameters as independent variables. The results indicated that the final model achieved a distance prediction accuracy of 0.949 for primary arterial roads. The variables of density (with a negative influence), stop time, operational speed, and queue length had a significantly greater impact on predicting the functional distance of primary arterial roads. Specifically, higher building density is associated with a decrease in the optimal spacing of these roads, whereas longer stop times and greater queue lengths contribute to increased spacing requirements. Moreover, an increase in land use density and the functional distance of roads leads to a higher increase in vehicle queue length, particularly in the three-ring network with a distance of 800 meters between roads. Additionally, as similar values increase, the stop time of vehicles also rises.

Keywords: Building density, distance of arterial roads, delay, flow rate, travel time, queue length

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1. Introduction

Urban roads serve as vital arteries within the city's framework, playing a crucial role in urban communication, community health, increasing citizen satisfaction, and improving environmental quality [Najafi Moghaddam Gilani et al., 2022]. Roads are integral to the geometric layout of cities [Abdi et al., 2019], urban development, and all aspects related to urban areas [Behbahani et al., 2017]. Urban development may include improvements in infrastructure [Adeli et al., 2023], transportation systems [Bargegol et al., 2018], flow rates [Bargegol et al., 2016], pedestrian systems [Behbahani et al., 2017; Fan et al., 2022], and also changes in urban form. Furthermore, urban roads are essential components of the transportation system, occupying a significant portion of the urban landscape.

Urban roadways typically fulfill multiple roles, some of which may conflict with each other, while the combination of roles can sometimes enhance social interactions among citizens [Roess et al., 2019]. Mobility, accessibility, and social interaction are the three main functions of urban roads and are used as key criteria for their classification. Urban road networks can only effectively perform their functions if they maintain the network structure and functional hierarchy and ensure an appropriate distance between roads of the same functional category [Bargegol et al., 2017].

Proper road spacing and network structure can improve overall efficiency, provide easy access to different areas of the city, prevent traffic congestion, enhance service levels, reduce costs, and improve both the environment and the health of citizens. Various regulations report different values for the functional distance between roads. However, these regulations do not adequately consider the impact of density, land use types, and the simultaneous application of these factors on road functionality when determining road distances. Ignoring these factors can waste significant land resources for replacing various types of roads, increase added value, squander financial resources for road construction, and lead to increased air and noise pollution due to neglecting network traffic parameters [Long and Carlsten, 2022].

In many cities, the land allocated for roads significantly exceeds recommended standards, and not optimizing the use of land designated for roadways may lead to increased construction and land acquisition costs, resulting in skyrocketing prices for land adjacent to the roads under study and development [Yii et al., 2022]. Moreover, examining the relationships between the various functions and land use densities can greatly assist in optimizing the spacing of functional roads. Therefore, this study aims to achieve optimal performance levels for roads by applying various traffic parameters and land use densities.

This research will investigate the optimal distance of primary urban arterial roads under varying building densities to address the lack of specific regulations on this matter and fill the gap in determining standards that guide urban planners and traffic engineers in designing new roads, urban development, and resolving existing traffic issues. Accurately determining influential parameters can significantly reduce costs and enhance the economic efficiency of urban road design and upgrades.

2. Literature Review

Numerous studies have been conducted on the impact of urban network forms on traffic flow, many of which have examined the distance between roads. Various simulation methods have also been employed in these studies to determine different urban network configurations. Simulation is a valuable tool for optimizing road space allocation, reduce pollution in cities, enhance road safety, and consider user needs during decision-making processes [Pursula, 1999]. Another application of simulation includes determining intersection forms [Diakaki et al., 2003].

In 1996, Krein developed a model to establish a connection between urban road shapes and travel demand, focusing primarily on travel time [Crane, 1996]. In the same year, Brindle discussed the application of functional hierarchy in real street systems, describing the street system based on separate functionalities [Brindle, 1996]. Snellen, Burgers, and Tijmense modeled the relationship between urban structure, transportation network shape, and mode selection for repetitive trips in 2002 [Snellen et al., 2002]. In 2009, Zhi and Levinson investigated various urban transportation networks using a simulation model [Xie and Levinson, 2009]. In 2012, Yang and colleagues examined traffic capacity across different distances, concluding that the length of these areas depended on conflicting flows [Yang et al., 2012]. They further established that the capacity of road spacing relied on the ratio of volume to the length of the conflicting area [Yang, et al., 2013].

In 2013, Wei and Wanjing studied a lane allocation method to enhance road spacing performance [Wei and Wanjing, 2013]. In 2014, Liu and colleagues analyzed traffic movements near conflicting areas involving a mix of fast and slow vehicles [Liu et al., 2014]. Also in 2014, Kozuma et al. focused on analyzing driving behavior at different road distances [Kusuma et al., 2015]. In 2016, Li and colleagues presented an integrated model that considered land use and traffic network design [Li et al., 2016]. In 2018, Gholami and colleagues evaluated the impact of urban land use on traffic volume to organize and redistribute these spaces [Shakibaei et al., 2015]. Jabari and Behzadi in 2019 used a traffic simulator to analyze travel demand based on data and GIS analysis [Jabbari and Behzadi, 2019]. Shen and colleagues in 2020 studied the interactions between land use and parking to examine the effects of their dissemination on traffic congestion [Shen et al., 2020]. Finally, in 2021, Yang and his team explored the impact of various land uses on urban accidents, investigating the relationships between these two types of variables using various meta-heuristic algorithms [Yang et al., 2021].

Compared to prior studies, such as those by Xie & Levinson (2007) who developed a gravity-based network design model, and Yang et al. (2015) who explored spatial dynamics of road spacing based on urban growth, the current study contributes by incorporating simulation-based traffic parameters into a multi-variable regression framework. While previous models largely focused on geometric or theoretical optimization principles, our approach integrates operational traffic performance (e.g., delay, queue length, stop time) directly derived from micro-simulation.

Moreover, models such as that of Xie & Levinson often assumed idealized conditions and minimized generalized travel cost, whereas the proposed model accounts for complex traffic phenomena and spatial congestion effects under varying density scenarios. Unlike Yang et al., who analyzed static spatial layouts, our method dynamically tests multiple densities and spacing configurations through scenario-based simulation.

Thus, this study enhances the practical applicability of road spacing models by combining land use density with real-time traffic dynamics.

3. Methodology

Figure 1 illustrates the research flowchart. The main objective of this study is to examine the impact of density and optimal spacing of primary arterial roads on the traffic performance of a radial-ring road network. To achieve this, building densities ranging from 100% to 250% and road spacings of 800 to 1200 meters were defined, resulting in the creation of two distinct radial-ring networks.

Several reasons justify the selection of these parameters. First, equal land areas were considered for drawing both networks. Second, according to urban road design regulations, the minimum functional distance between primary arterial roads is set at 800 meters. Lastly, selecting functional distances shorter than 800 meters would reduce the spacing between secondary arterial roads to less than the standard conflicting area length of 250 meters as defined in road capacity regulations.

Consequently, the urban network was drawn using AutoCAD and transferred to the AIMSUN simulation software for traffic analysis. After simulating the various networks, seven different traffic parameters were extracted: delay, flow rate, density, operating speed, queue length, travel time, and stopping time. Subsequently, a multiple regression method was employed to develop a predictive model for the spacing of arterial roads.

A multivariate regression method was used to develop the model predicting the functional distance between arterial roads. This method is employed when predicting a dependent variable using several independent variables. It predicts a relationship between independent and dependent variables using a polynomial. Even if no perceivable physical relationship exists between the variables, they may still be correlated through a mathematical relationship. Although this function may be physically meaningless, it can still be highly valuable for predicting the values of one variable based on related data from other variables. To present a multivariate regression model, a set of statistical tests is necessary. These include verifying the normality of parameter values, ensuring the absence of multicollinearity among independent variables, confirming the existence of a significant model relationship, and establishing the significance of each parameter.

To determine whether the regression has successfully predicted the dependent variable, the values of the coefficient of determination, adjusted coefficient of determination, and root mean square error (RMSE) were calculated based on equations (1) to (3):

$$\mathrm{R}^2=\frac{\left(\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{y}_{\text{actual}}-\bar{\mathrm{y}}_{\text{actual}}\right)\times\left(\mathrm{y}_{\text{predicted}}-\bar{\mathrm{y}}_{\text{predicted}}\right)\right)^2}{\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{y}_{\text{actual}}-\bar{\mathrm{y}}_{\text{actual}}\right)^2\times\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{y}_{\text{predicted}}-\bar{\mathrm{y}}_{\text{predicted}}\right)^2} \tag{1}$$

$$\mathrm{R}^2_{\ \text{adjusted}}=1-\frac{(1-\mathrm{R}^2)(\mathrm{N}-1)}{\mathrm{N}-\mathrm{p}-1} \tag{2}$$

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}\left(\mathrm{y}_{\text{actual}}-\mathrm{y}_{\text{predicted}}\right)^2}{\mathrm{N}}} \tag{3}$$

Where R2is the coefficient of determination, R2adjusted،is the adjusted coefficient of determination, RMSE is the root mean square error, N is the total number of samples, yactual are the laboratory values,$\bar{y}$actual is the average of the laboratory values, ypredicted are the predicted values, and$\bar{y}$predicted is the average of the predicted values [Behbahani et al., 2020; Najafi Moghaddam Gilani, et al., 2021; Najafi Moghaddam Gilani et al., 2021; Gilani et al., 2021;Bargegol et al., 2022].

In this study, the variable for the distance of primary arterial roads was considered as the dependent variable, while delay, flow rate, density, travel time, stop time, operational speed, and queue length were considered as independent variables.

4. Results and Analysis

4.1. Simulation

In this section, the results of traffic parameters obtained from travel volume loading are discussed. Using various statistical models, mathematical relationships are presented for two variables: building density and the distance between primary arterial roads. Figures (2) and (3) illustrate the queue lengths obtained from simulating the studied networks, for a dual-ring network with a road spacing of 1200 meters and a triple-ring network with a road spacing of 800 meters, respectively. Analysis of the data from these charts shows that in both the dual-ring and triple-ring networks, as building density increases from 100% to 250%, the average queue length of vehicles significantly increases. This increase is approximately linear in both networks, indicating a rise in transportation demand and pressure on the traffic network as building density increases. Specifically, in the dual-ring network with a road spacing of 1200 meters, the chart indicates an exponential increase in vehicle queue lengths as building density rises. In Variant 4 (density 250%), the average queue length of vehicles exceeds 7000, representing the highest congestion level among variants. In the triple-ring network with a road spacing of 800 meters, the chart reveals that the queue lengths in the initial variants (100% and 150%) increase at a lower rate, while at Variant 200%, the increase occurs at a severe rate, and in Variant 250%, it moderates again.

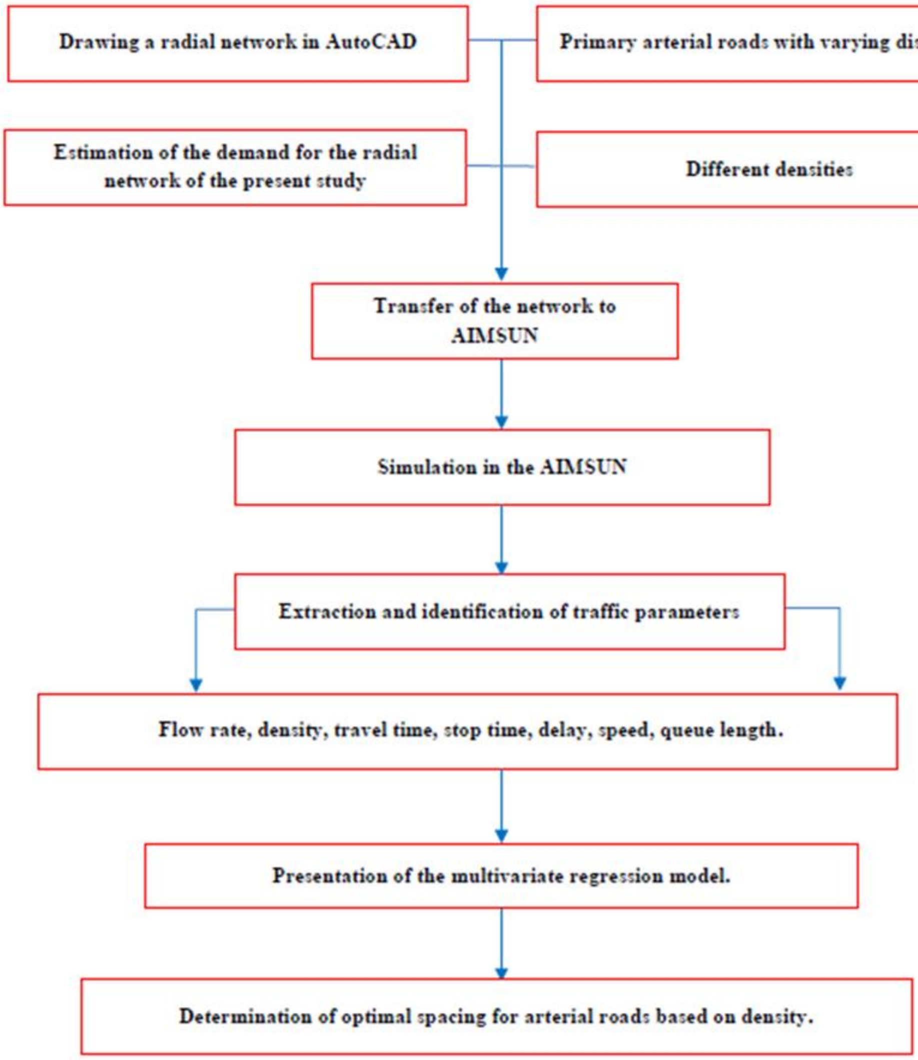

Figure 1. Research methodology flowchart illustrating the simulation and modeling process

Figures (4) and (5) display the results of stop times obtained from simulating the studied network for a triple-ring network with a road spacing of 800 meters and a dual-ring network with a road spacing of 1200 meters, respectively. Analysis of the stop time charts reveals that as building density increases, stop times also increase in both the dual-ring and triple-ring networks. This increase is more pronounced in the dual-ring network, which suggests a significant impact of higher density on traffic efficiency.

In the dual-ring network with a road spacing of 1200 meters, stop times rise from approximately 200 seconds in Variant 1 (density 100%) to over 300 seconds in Variant 4 (density 250%). This increase reflects the pressure on the traffic network and a decrease in its efficiency in handling traffic load. Conversely, in the triple-ring network with a road spacing of 800 meters, the stop times increase from about 60 seconds in Variant 1 to approximately 140 seconds in Variant 4. While the increase in stop time demonstrates the impact of building density on network efficiency, the rate of increase is less pronounced than that observed in the dual-ring network.

Figures (6 and 7) display the results of travel time obtained from the simulation of the studied network for two configurations: a three-ring network with a distance of 800 meters and a two-ring network with a distance of 1200 meters, respectively. The analysis of the travel time graphs indicates that as building density increases in both the three-ring and two-ring networks, travel time also steadily increases. This rise illustrates the direct effect of building density on the efficiency of the traffic network.

In the three-ring network with a road spacing of 800 meters, travel time escalates from about 169 to 180 seconds in Variant 1 to approximately 240 seconds in Variant 4. In the two-ring network with a road spacing of 1200 meters, travel time increases from about 340 seconds in Variant 1 (100% density) to more than 440 seconds in Variant 4 (250% density). This increment suggests that as density increases, traffic becomes heavier, and consequently, travel time increases. While the increase in travel time is consistent in both networks, it is less pronounced in the three-ring network, indicating better tolerance to increased congestion compared to the two-ring setup.

Figures (8 and 9) display the results of the functional speed obtained from the simulation of the studied network for two configurations: a two-ring network with a distance of 1200 meters and a three-ring network with a distance of 800 meters for arterial passages, respectively. The analysis of the speed charts shows that as building density increases in both the two-ring and three-ring networks, the speed of cars decreases similarly. This decline in speed indicates an increase in traffic density and a decrease in the efficiency of the traffic networks.

In the two-ring network with a road spacing of 1200 meters, the speed has decreased from about 28 km/h in Variant 1 (100% density) to about 23 km/h in Variant 4 (250% density). This reduction suggests a heavier traffic load and a lower network efficiency under high density conditions. In the three-ring network with a road spacing of 800 meters, the speed decreases from about 18 km/h in Variant 1 to about 11 km/h in Variant 4. This more substantial decrease highlights the network's lower efficiency in managing congestion, especially at higher density levels.

Figures (10 and 11) show the results of the delay obtained from the simulation of the studied network for two networks, three rings with a distance of 800 meters and a network of two rings with a distance of 1200 meters, respectively. Time delay diagrams show that as the building density increases in both the two-ring and three-ring networks, the delay time also increases. This increase in latency indicates a higher traffic load and a decrease in the efficiency of the network in processing traffic. In the 3-ring network with a distance of 800 meters, the latency has increased from about 100 seconds in Variant 1 to about 160 seconds in Variant 4. This is a smaller increase than in the two-ring network, but it still reflects the negative impact of congestion on the network. In the two-ring network with a distance of 1200 meters, the latency increases from about 240 seconds in Variant 1 to more than 360 seconds in Variant 4. This continuous increase indicates that the network is having trouble dealing with high density.

Figures (12 and 13) display the results of the flow rate obtained from the simulation of the studied network for two configurations: a two-ring network with a distance of 1200 meters and a three-ring network with a distance of 800 meters for arterial passages, respectively. The flow rate charts show that in both networks, the number of vehicles passing through the grid (traffic flow) has increased as building density has increased. This increase indicates the networks' ability to handle a larger volume of traffic, but it also suggests increased pressure on the infrastructure.

In the 1200-meter two-ring network, the flow rate has increased from about 24,000 cars per hour in Variant 1 to over 27,000 cars per hour in Variant 4. This increase demonstrates the network's high capacity to process traffic efficiently. In the 800-meter three-ring network, the flow rate rises from about 28,000 cars per hour in Variant 1 to approximately 34,000 cars per hour in Variant 4. This further increase underscores the network's enhanced capability to manage traffic at high densities. Figures (14 and 15) show the results of the density obtained from the ¬simulation of the studied network for two networks of two rings with a distance of 1200 meters and a network of three rings with a distance of 800 meters of arterial passages, respectively. Density diagrams show that as building density increases, traffic density increases in both two-ring and three-ring networks. This increase indicates more pressure on traffic networks and reduced efficiency. In the two-ring network with a distance of 1200 meters, the density increases from about 7 vehicles per km in Variant 1 to about 11 vehicles per km in Variant 4. This indicates a significant increase in traffic on this network, which can lead to a decrease in speed and increased latency. In the three-ring network with a distance of 800 meters, the density increases from about 5 vehicles per km in Variant 1 to more than 10 vehicles per km in Variant 4. This increase, however severe, indicates the network's ability to process higher volumes of traffic.

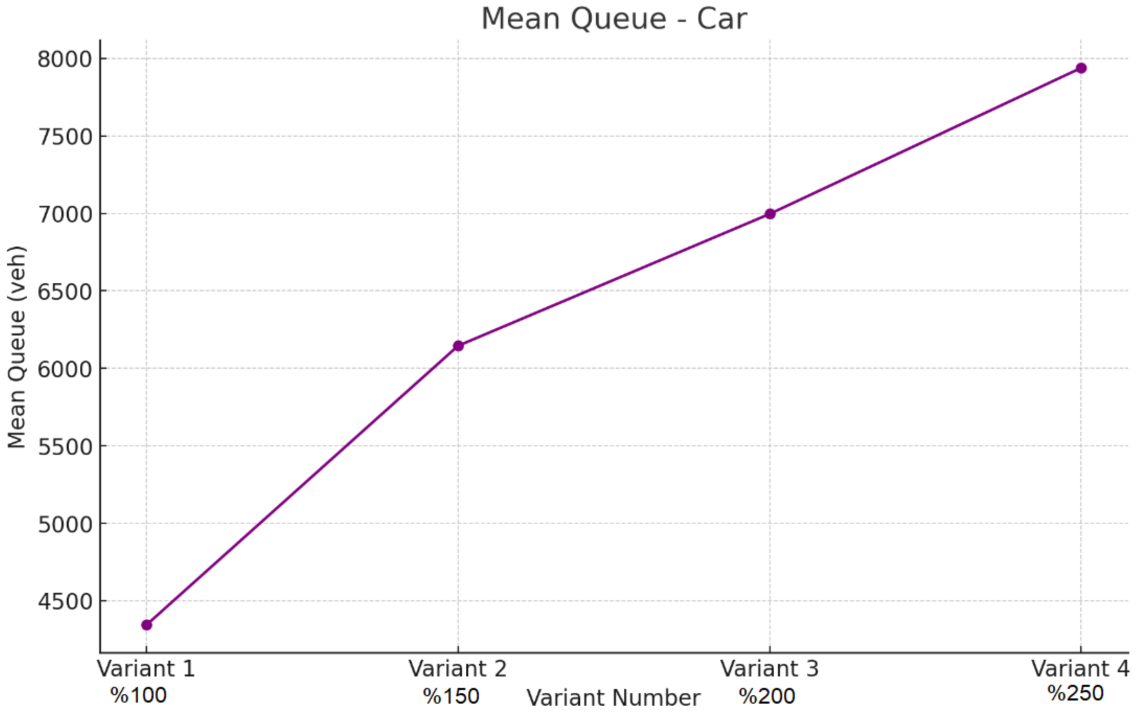

Figure 2. Results of the queue length of the simulated network of two rings with a distance of 1200 meters

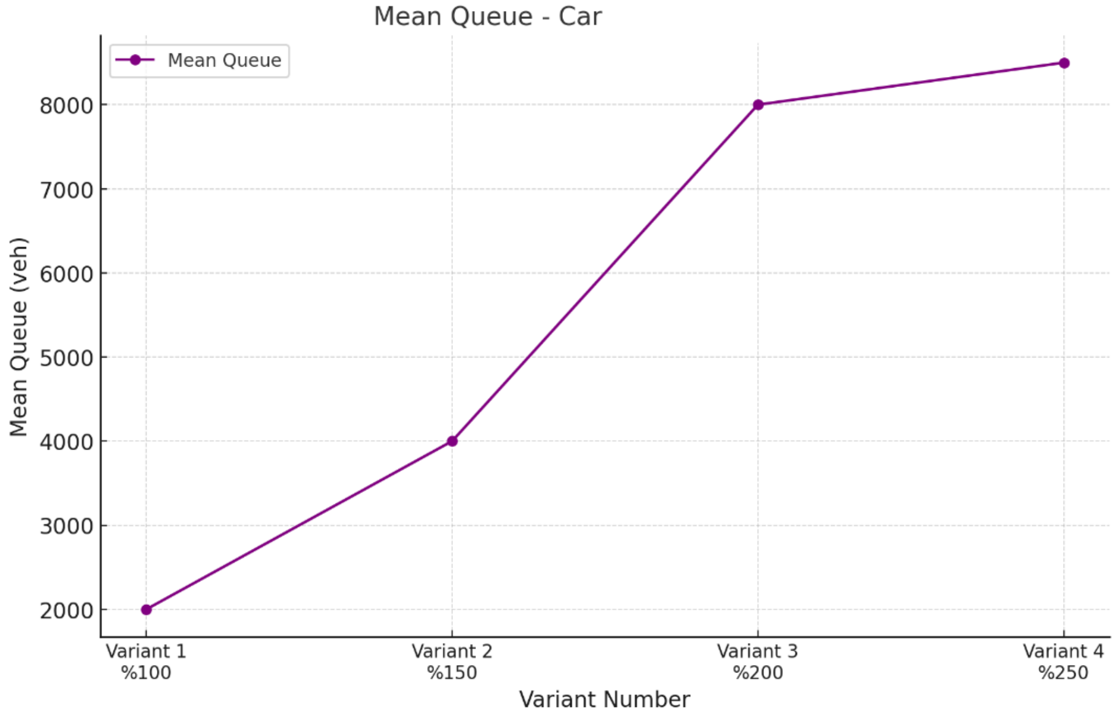

Figure 3. The results of the queue length of the simulated network of three rings with a distance of 800 meters

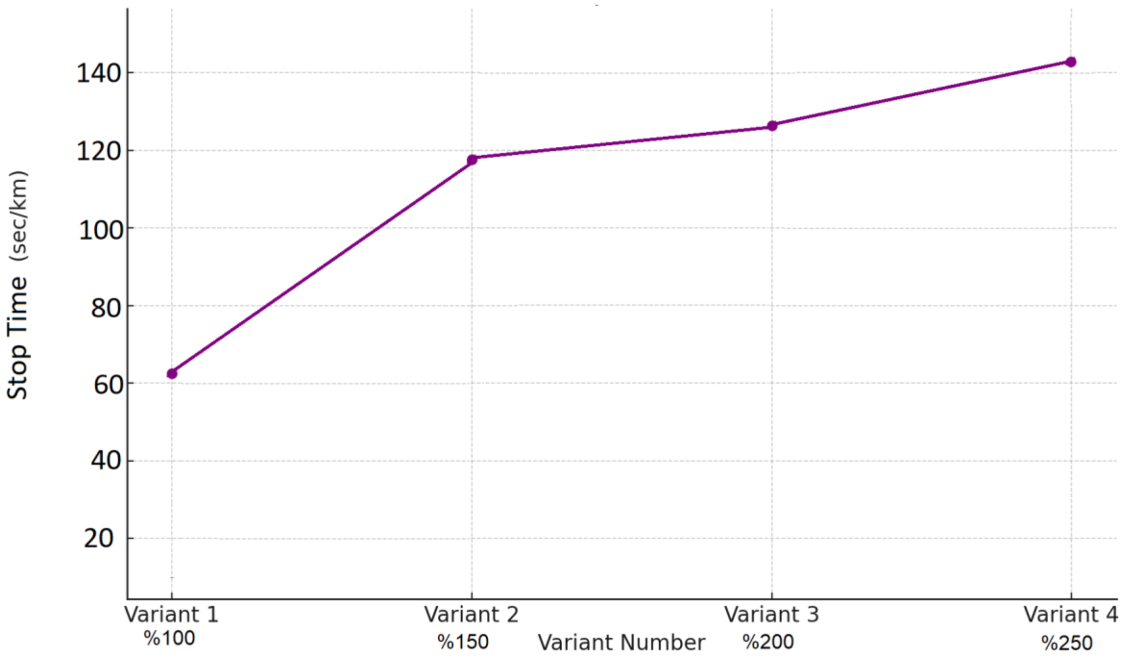

Figure 4. Stop time results (sec/km) for the three-ring network with 800-meter spacing under varying building densities

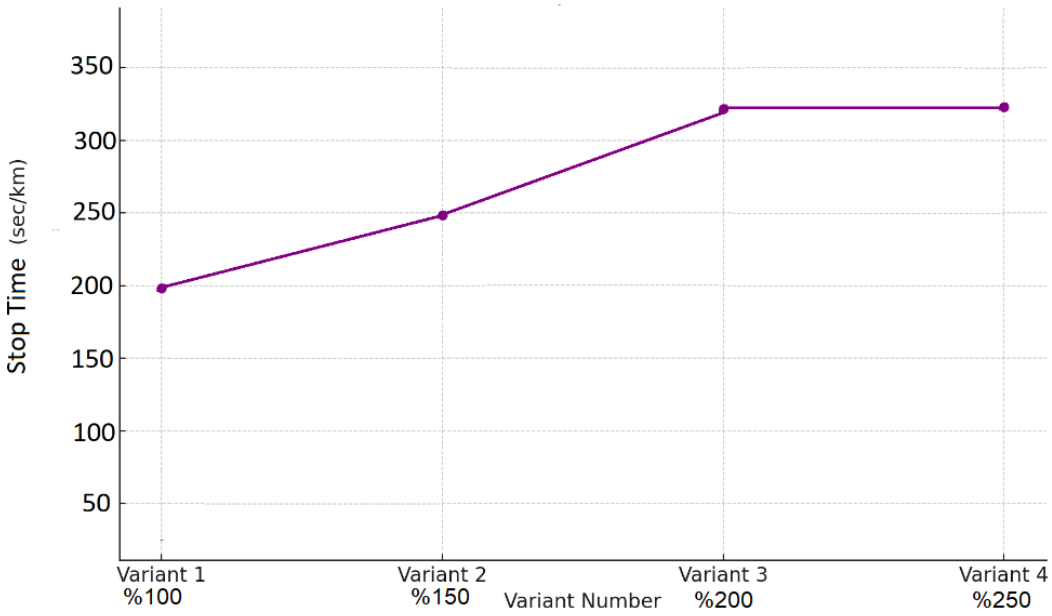

Figure 5. Stop time results (sec/km) for the two-ring network with 1200-meter spacing across different density scenarios

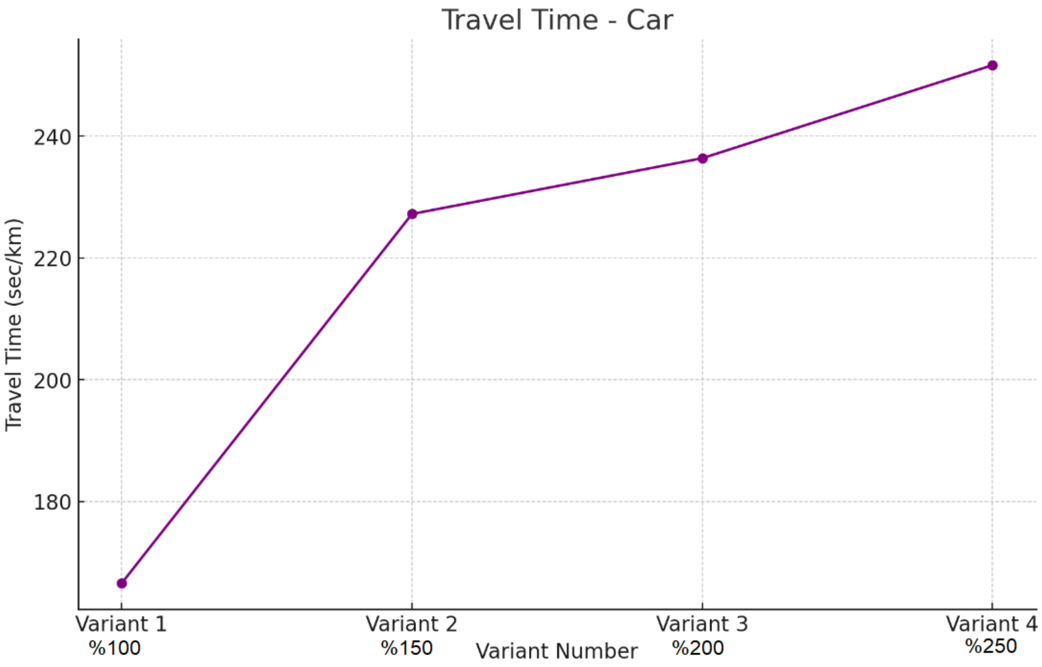

Figure 6. Travel time (sec) simulation results for the three-ring network with 800-meter arterial spacing under various density conditions

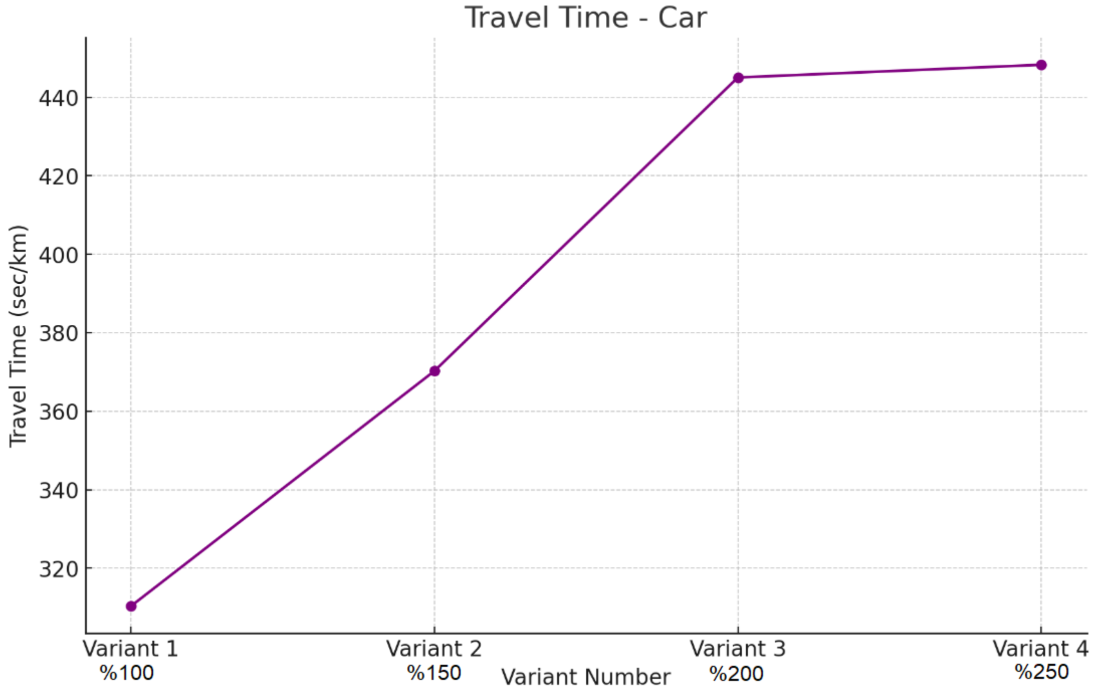

Figure 7. Travel time (sec) simulation results for the three-ring network with 1200-meter arterial spacing under various density conditions

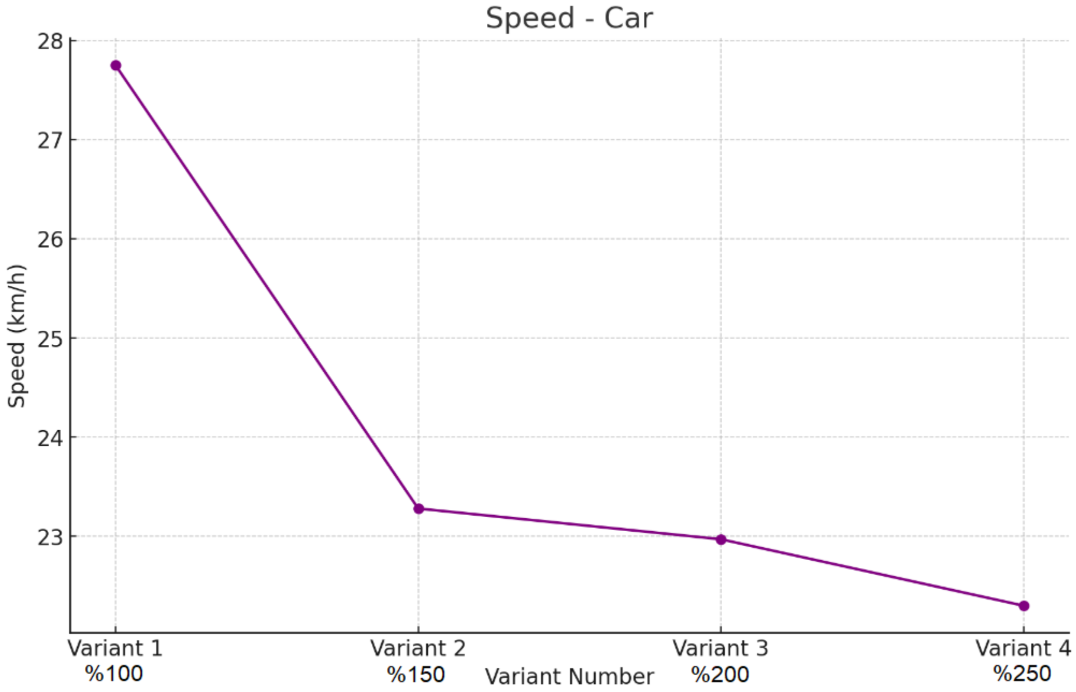

Figure 8. Functional speed (km/h) versus building density for the two-ring network with 1200-meter spacing

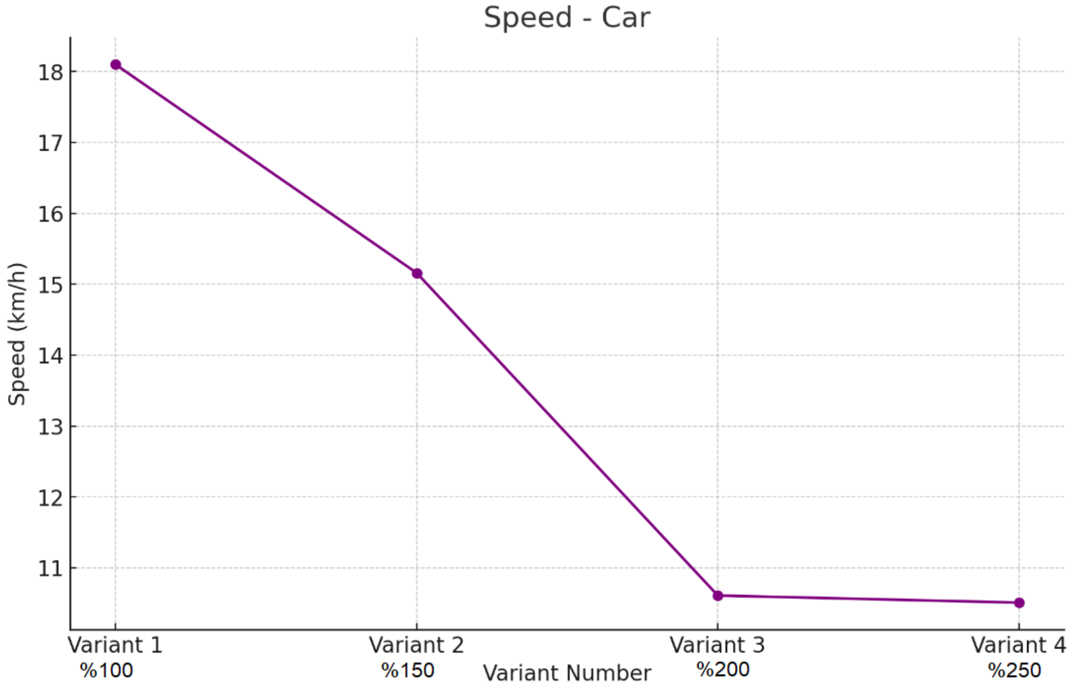

Figure 9. Functional speed (km/h) versus building density for the two-ring network with 800-meter spacing

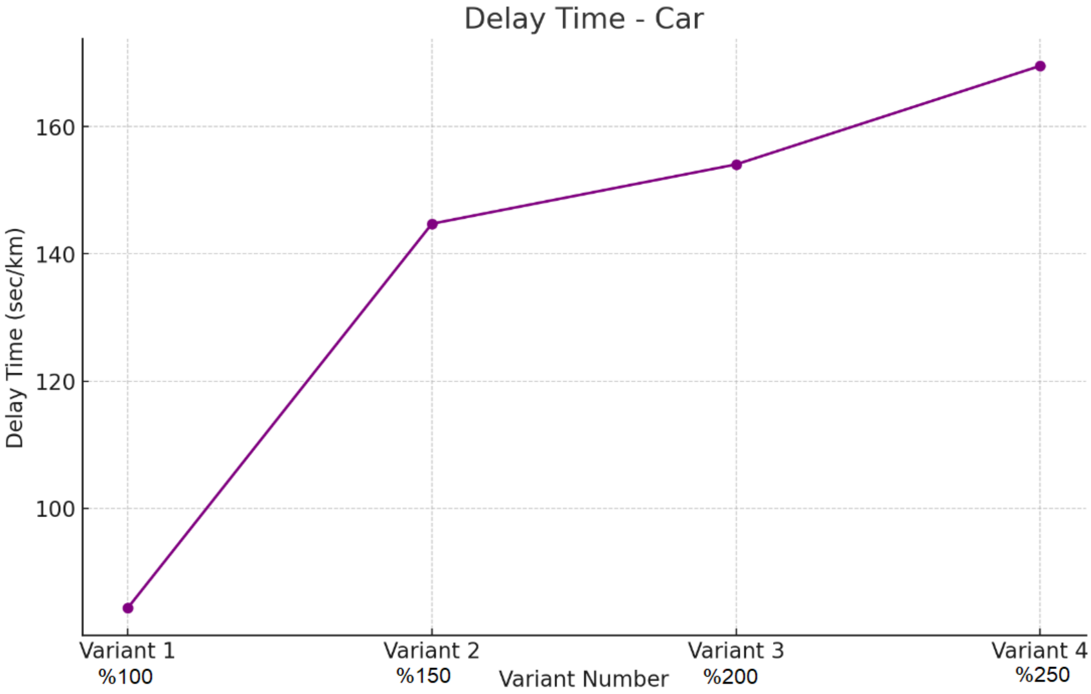

Figure 10. Relationship between building density (veh/km) and functional distance (meters) for the 2-ring network configuration. The results show that higher density reduces optimal arterial spacing

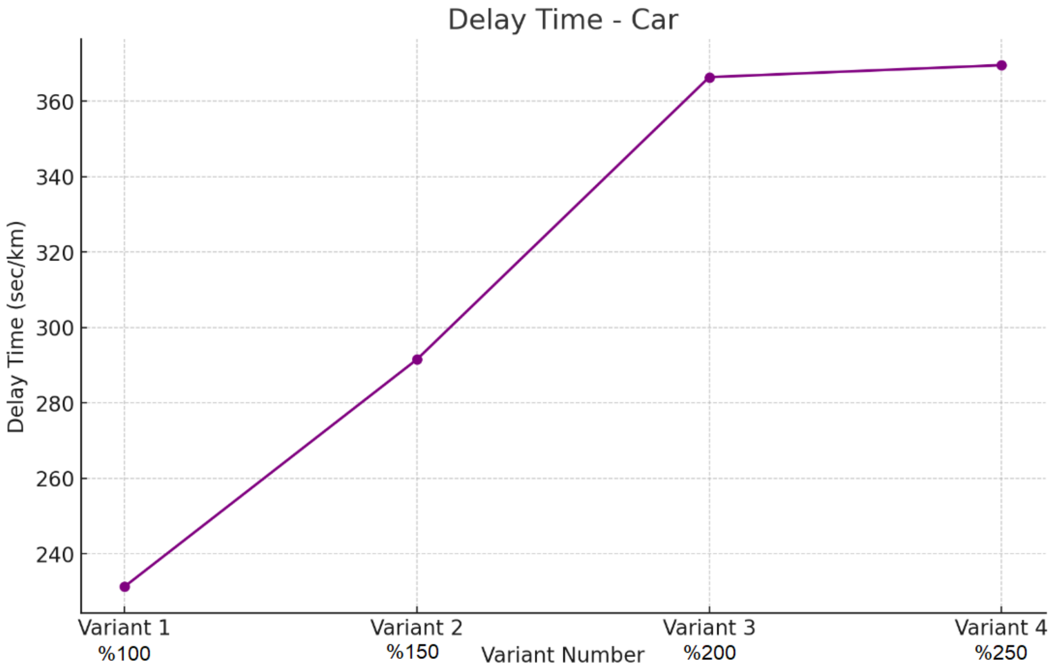

Figure 11. Simulation delay results of the studied network of two rings with a distance of 1200 meters

4.2. Presenting a Model of Functional Distance of Roads

In this section, the multivariate regression modeling (MVR) method is used to develop a model for predicting the functional distance of first-degree arterial passages (USD) in radial networks with annular texture. Table (1) presents the coefficients of the multivariate regression model along with the significance tests of these coefficients. The coefficients of the regression model are referred to as non-criterion coefficients. As indicated by the data in this table, the coefficients for the variables of density (145.21), stopping time (12.12), functional speed (19.51), and queue length (55.31) are higher than those for the variables of flow rate (0.02), delay (3.59), and travel time (0.79). This suggests that changes in density, stopping time, functional speed, and queue length have a more significant impact on the functional distance of the first-degree arterial passages (USD). According to the data from this table, it can be concluded that all variables used in this study significantly affect the functional distance of the first-degree arterial passages in radial networks with annular texture.

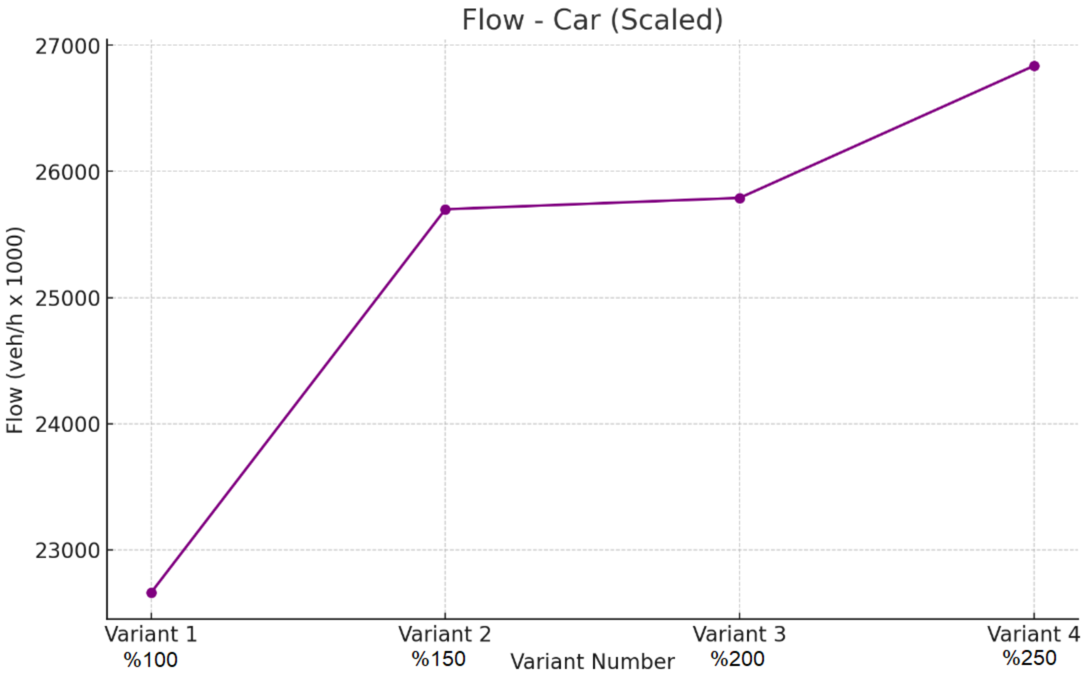

Figure 12. Results of the simulated flow rate of the studied network of two rings with a distance of 1200 meters

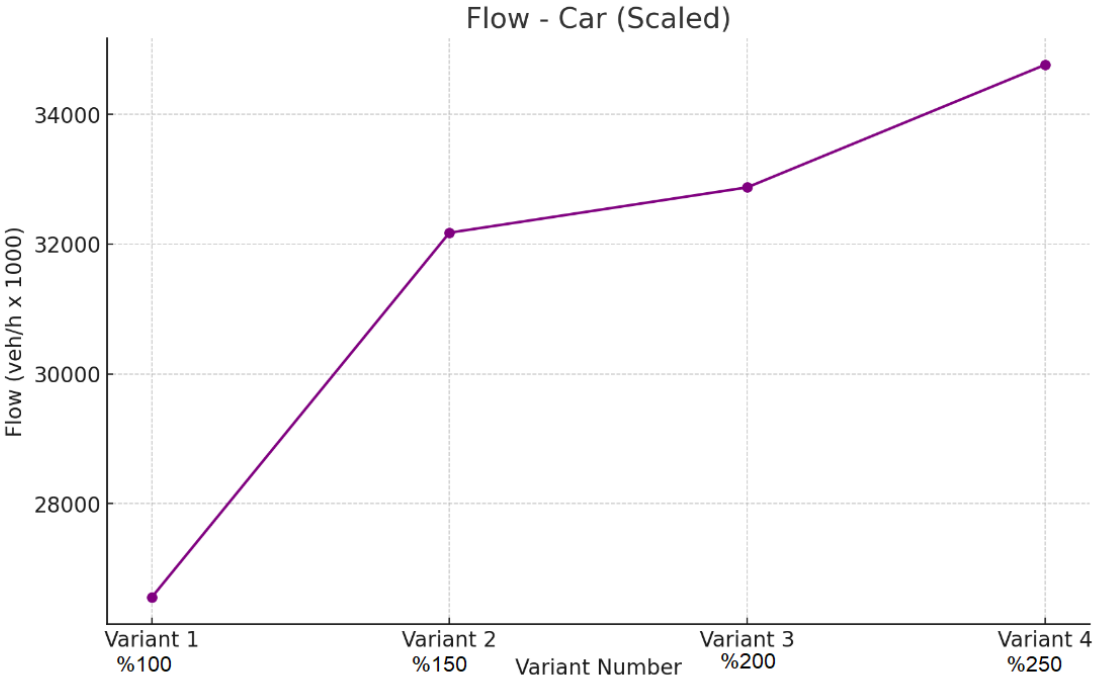

Figure 13. Results of the simulated flow rate of the studied network of three rings with distance of 800 m

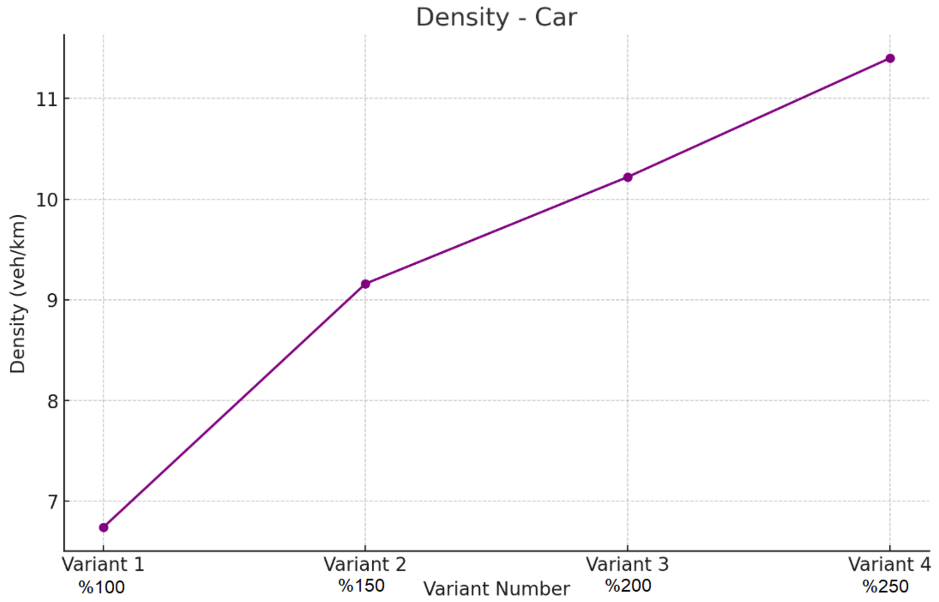

Figure 14. Results of the simulation density of the studied network of two rings with a distance of 1200 m

Table 1. Coefficients of the proposed regression model

Model	Non-standard coefficients		Benchmark Coefficients	t	p-value
	Coefficient	Standard			
Fixed number	21.93	2174.55	---	1.332	0.000
Flow Rate (veh/h)	0.02	0.164	0.111	0.151	0.001
Functional Speed (km/h)	-19.51	46.945	0.236	-0.590	0.000
Delay (sec/km)	-3.59	21.624	0.121	-0.173	0.000
Stop time (sec/km)	-12.12	30.664	0.342	-0.437	0.023
Travel Time (sec)	0.79	0.402	0.724	1.887	0.000
Density (veh/km)	-145.21	186.013	0.564	-0.785	0.0013
Queue Length (veh)	55.31	51.599	0.501	1.073	0.000

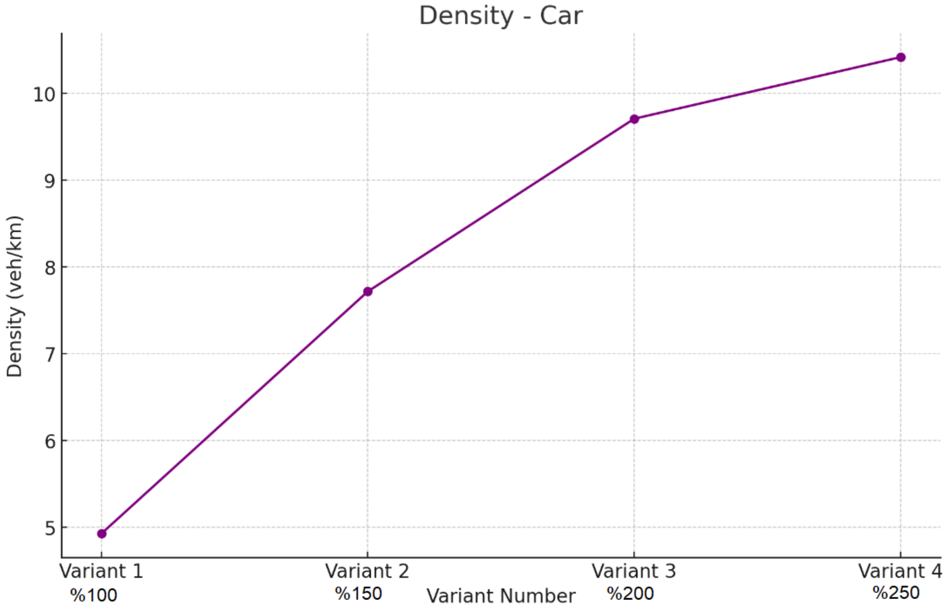

Figure 15. Results of the simulation density of the studied three-ring network with a distance of 800 m

Based on the coefficients presented, it can be said that the regression model presented in this study is:

$$\begin{aligned}\mathrm{USD} = 2897.365 + 0.025f - 27.702\,S \\ - 3.734De - 13.395ST \\ + 0.758TT - 146.001D \\ + 55.364QL\end{aligned} \qquad (4)$$

In which: functional distance of first-order arterial passages, flow rate, functional speed, delay, stopping time, travel time, USDfSDe STTTand D density and QL of queue length.

The results of the analysis of variance are presented in Table (2). The F parameter in this table determines whether the model adequately describes the dependent variable overall. This is assessed by dividing the mean squares of the regression and the residuals. The mean squares are calculated by dividing the sum of the squares of the regression (the sum of the squared differences between the model values and the mean line) and the residuals (the sum of the squared differences between the model values and the actual values) by their corresponding degrees of freedom.

The F-value is obtained by dividing the mean square of the regression by the mean square of the residuals, resulting in a value of 18.422. This value should be compared with the critical value from the F-distribution. Given a confidence level of 0.05 (α=0.05) and degrees of freedom equal to 7 for the regression and 14 for the residuals, the critical value from the F-distribution function is specified in relationship (5):

$$F \geq F_{(0.06)}(1.37) = 3.192 \qquad (5)$$

By comparing the obtained value for F and the critical value of the above statement, it can be seen that the hypothesis of non-fit of the proposed model is rejected by this test and it is probable that the model has been able to create a suitable fit between independent and dependent variables. In this case, it can be said that the relationship between independent and dependent variables is not random.

The summary of the proposed model is presented in Table (3). According to this table, the coefficient of determination (R^2) for the model in this study is 0.949. The square root of this parameter, which is the multiple correlation coefficient (R), is 0.974. Additionally, the value of the adjusted coefficient of determination is 0.897. The adjusted coefficient of determination is particularly useful in multivariate regression, as it accounts for the potential increase in R^2 due to the mere addition of independent variables, regardless of their actual relevance. This adjustment considers both the number of independent variables and the sample size. The adjusted coefficient of determination is commonly used to compare different models, adjusting for variations in the number of variables included in each model. Furthermore, the root mean square error (RMSE) for the model is 338.73.

Based on the model outlined in relation (4), the observed values, the predicted values derived from the model, and the residuals (the differences between observed and predicted values) are calculated. As illustrated in Figure (16), a comparison between the model's predicted values and the actual observed values is presented. One critical assumption of the multivariate regression method is that the residuals should follow a normal distribution. This assumption is particularly important when the number of data points is limited. Figure (17) displays the distribution of the residual values. As observed in this figure, the distribution of the residuals approximates a normal distribution.

Table 2. Analysis of Variance of the Proposed Model A

Model b	Total Squares	Degree of Freedom	Average Squares	F-Value	P-Valuea
Regression	147967.521	7	2113.939	18.422	0.001
Remains	80320.489	7	1147.64		
Total	1560.000	14			

Table 3. Summing up the results of the model presented by multivariate regression method

Model	Results
Multiple correlation coefficient (R)	0.974
Coefficient of Determination (R2)	0.949
Adjusted coefficient of determination	0.897
Root mean square of the line (RMSE)	338.73

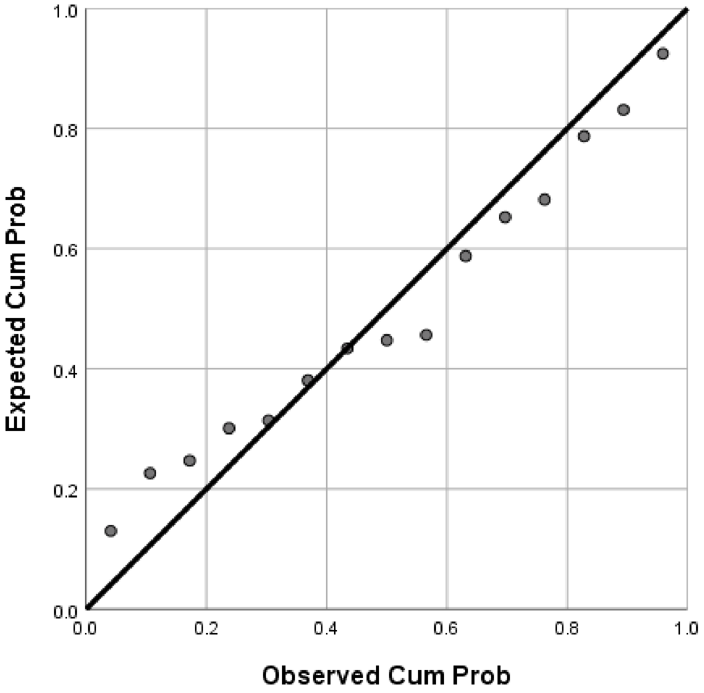

Figure 16. Comparison of the actual and predicted values of the functional distance of first-degree arterial passages in the radial-annular network

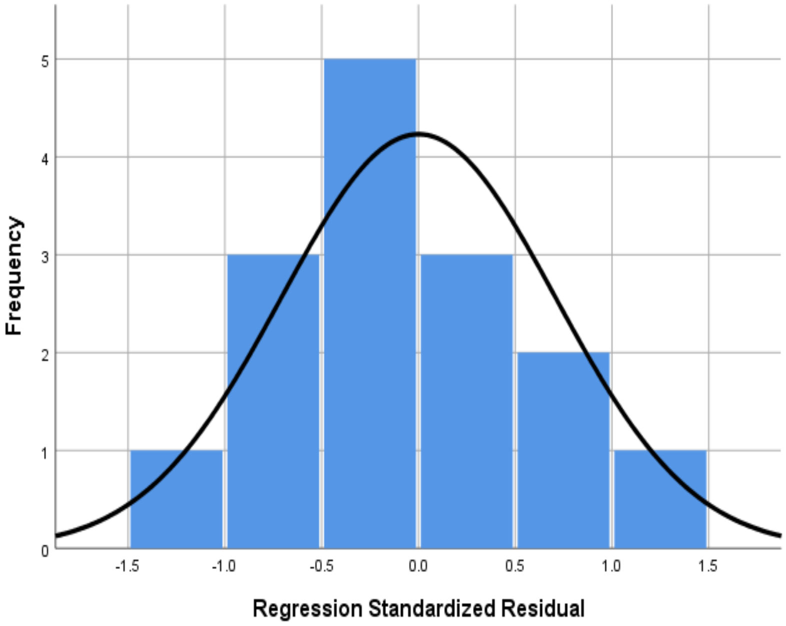

Figure 17. Normal distribution of residues in the functional distance model of first-degree arterial passages in radial-annular network

4.3. Sensitivity Analysis of the Regression Model

To assess the robustness of the developed multiple regression model and to better understand the impact of variations in input variables on the predicted functional distance, a sensitivity analysis was performed. In this analysis, each of the independent variables was altered by ±10% from its mean value, while all other variables were kept constant. The resulting change in the predicted output (functional distance) was then calculated using the model's regression coefficients.

Among all variables, "building density" showed the strongest influence on the model’s output. For instance, in the two-ring network (with 1200-meter spacing), a 10% increase in building density (from an average of 9.38 veh/km) resulted in an approximate "136.2-meter" decrease in predicted arterial distance. In the three-ring network (with 800-meter spacing), a 10% increase in density (mean 8.21 veh/km) led to a "119.2-meter" reduction in the functional distance.

This finding confirms the model’s sensitivity to land-use intensity and the significant role of density in shaping the functional layout of urban arterial roads. The analysis also supports the reliability of the model in responding to real-world variability and enhances its value for practical urban planning applications.

4.4. Model Validation and Overfitting Check

Given the limited number of data points (only four observations), traditional k-fold cross-validation or hold-out testing was not feasible. Attempts to apply both 5-fold and Leave-One-Out Cross-Validation (LOOCV) resulted in undefined R^2 values due to insufficient test samples in each fold.

To address potential concerns about overfitting, we relied on the analysis of residuals and the comparison of actual versus predicted values, as illustrated in Figures 16 and 17. The close alignment between observed and predicted values and the approximately normal distribution of residuals support the validity and stability of the model.

Nonetheless, we acknowledge the limited sample size as a constraint and recommend that future research includes more simulation scenarios or empirical data points to enable robust cross-validation procedures.

4.5. Comparative Evaluation of 800m and 1200m Configurations

To better understand the impact of arterial spacing on network performance, the results of the two simulated configurations—800m (three-ring) and 1200m (two-ring)—were directly compared across several key traffic indicators, including functional speed, delay, queue length, and density, as summarized in Table 4.

The results show that the 800-meter configuration generally yields better traffic performance, especially in terms of reduced delay and queue length. This suggests that shorter spacing between primary arterial roads can help alleviate congestion in medium-density urban environments. However, the 1200-meter configuration offers a more compact network that may be advantageous in low-density settings where land acquisition is constrained. Therefore, the optimal spacing should be chosen based on the balance between available space and desired traffic efficiency.

Table 4. Comparison of average traffic metrics for 800 m vs. 1200 m arterial spacing

Parameter	Average (800m)	Average (1200m)	% Change
Functional Speed (km/h)	25.1	24.1	4.0
Delay (sec/km)	113.6	138.2	21.7
Queue Length (veh)	6050.2	6608.0	9.2
Stop Time (sec/km)	101.2	112.3	11.0

5. Conclusion

The main purpose of this study was to present a multivariate regression model for the functional distance between first-order arterial roads in a radial network with a circular texture. The key findings of the study are as follows:

Queue Length: As the functional distance between roads increases, the length of vehicle queues also increases. However, this increase is more pronounced in the three-ring network with a first-class road distance of 800 meters and a density of 200%. Conversely, the two-ring network with a functional distance of 1200 meters demonstrates better queue length performance compared to the three-ring network.

Stopping Time: The three-ring network with a distance of 800 meters between first-class roads exhibits better stopping time performance than the two-ring network.

Travel Time: With an increase in the functional distance of first-class arterial roads, vehicle travel time also increases. This increase is more significant in the two-ring network, and urban networks with a minimum functional distance of 800 meters between first-class arterial roads show better travel time performance.

Network Density: The regression results show a negative correlation between building density and functional distance. This implies that as building density increases, the optimal spacing between first-order arterial roads tends to decrease. Therefore, urban areas with higher land-use intensity may benefit from a more compact road network configuration to maintain efficient traffic performance.

Model Accuracy: The accuracy of the final model for predicting the distance of first-degree arterial roads using the multivariate regression method is 0.949. The variables of density, stopping time, functional speed, and queue length have a more significant effect on the functional distance of first-degree arterial roads compared to other traffic parameters.

These results highlight the complex interactions between road layout, traffic density, and network performance, emphasizing the importance of considering multiple variables when planning urban transportation networks.

6. Research Limitations

While this study provides valuable insights into the relationship between building density and the optimal spacing of primary arterial roads, several limitations should be acknowledged:

- Limited Sample SizeThe model was developed using a small number of simulation scenarios (only 4 data points per network configuration), which restricts the statistical power and generalizability of the findings.
- Simulation-Based Inputs: All data were derived from AIMSUN simulation rather than real-world traffic observations. Although the simulation was carefully designed, it may not capture the full complexity and variability of actual urban traffic conditions.
- Assumption of Uniform Conditions: The study assumed uniform land use densities and simplified radial-circular network geometries, which may not fully reflect the heterogeneity of real urban layouts.
- Lack of Temporal Dynamics: The simulations were static and did not account for temporal fluctuations such as peak vs. off-peak hours or seasonal variations in traffic demand.
- No External Validation: Due to the limited number of samples, cross-validation was not feasible in the classical sense, and the model's external predictive performance could not be formally assessed.

Future research should consider incorporating empirical traffic data, more diverse network typologies, and larger datasets to strengthen the model's applicability and statistical robustness.

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