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Modeling of mixed traffic flow operation mechanism considering the characteristics of electric bicycle

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Abstract

In recent years, China's economy has developed rapidly and transportation modes have become extremely diversified. Under the conditions of limited expansion of urban roads, the number of motor vehicles and electric bicycles has increased year by year, and the number of electric bicycles and bicycles has formed in the non-motor vehicle lanes. Mainly mixed non-motorized traffic flow. This is one of the reasons hindering the development of urban transportation. Therefore, an in-depth study of the characteristics of mixed non-motorized traffic flow and the capacity of non-motorized roads is of strongly significance to the development of non-motorized traffic flow theory and the solution of urban road traffic problems. This article studies the intersection of Lianhua Street and Xuesong Road in Zhengzhou, China， and the basic sections of non-motorized roads at the intersection of east, west, south and north entrances. The research is divided into the following aspects: The statistical characteristic parameters of mixed non-motor vehicle traffic flow are based on measured data Based on this, it mainly investigates the static and dynamic characteristics of the two types of vehicles (electric bicycles and traditional bicycles) and the characteristics of cyclists in the mixed non-motor vehicle traffic flow. Study the characteristics of mixed non-motor vehicle traffic flow and its main influencing factors. The research results show that the static characteristics of electric bicycles and traditional bicycles are quite different, which is mainly reflected in the difference in vehicle lateral width. Two methods of calculating the equivalent value of electric bicycles to traditional bicycles are proposed. The conversion coefficients for electric bicycles are 1.21 and 1.25, respectively. The research results are the average of the two methods. From a macro perspective, it studies the basic sections of mixed non-motor vehicle traffic flow speed characteristics, and takes the overall non-motor vehicle as the research object to establish a traffic flow with a mixed operation of traditional bicycles and electric bicycles. Through statistical analysis of data, the mixed non-motor vehicle The motor vehicle traffic flow is transformed into a non-motorized vehicle traffic flow based on traditional bicycles, and then the speed-density relationship are respectively analyzed for correlation, and regression equations are found. In addition, due to the different widths of the survey sections of the entrance roads, the final model between the speed and density of the east, west, south, north entrance roads is more comprehensive.The results show that the model has a good fitting effect on speed and density, and has certain reference significance.

Keywords

Electric bicycle,hybrid non-motor, three-parameter relationship,regression analysis.

1. Introduction

Electric bicycles have become the first choice of ordinary residents due to their advantages such as fast starting speed, high cost performance, and simple riding. However, electric bicycles are prone to running red lights at intersections, rushing through motorized lanes, and other traffic violations. Therefore, it is of great significance to study the safe driving and traffic control of electric bicycles.

The analysis and research on the characteristics of urban road traffic flow in foreign countries is more mature than that in China, but the focus of research is on a single motor vehicle flow. The traffic flow model system includes three types of models: macroscopic, mesoscopic, and microscopic. The mesoscopic traffic flow model studies the evolution of the speed distribution of vehicles. The cellular transmission mechanism is generally used as an important means to discretize traffic flow.Realize accurate and timely simulation of traffic flow.

Jin et al. combined the factors of bicycle type and cyclist characteristics to develop different numbers of speed-flow relationship models [1]. Nguyen and Lim proposed the operating model of electric bicycles by changing the influence of operating conditions and using Matlab-Simulink for calculations [2]. Borsche and Meurer studied the interaction between pedestrian traffic and cars. Describe the coupling conditions that can stimulate the corresponding macro-model and hybrid micro- and macro-systems [3]. Research by Dey et al. found that female commuter cyclists pay more attention to practicality; however, the choice mode of most commuters and cyclists is affected by road attributes [4]. Borsche and Meurer studied the interaction between pedestrian flow and road traffic. Propose coupling conditions that can stimulate the corresponding macro-model and hybrid micro-macro system [5]. Bai et al. used a generalized model to model a linear regression model through the conflict frequency of non-motorized lanes. The factors that influence the frequency of rear-end collisions are the running speed of electric bicycles and the width of the bicycle lanes [6]. Xu et al. used a linear regression model to propose the relationship between the average speed and the proportion of electric bicycles, and the average speed of pure electric bicycles or ordinary bicycles can be obtained [7]. Lee and Hatoyama provide a method to understand traffic flow conditions based on the characteristics of three traffic flow elements at the same time, aiming to provide information about transit traffic flow conditions [8]. Zhang and Yang studied the speed density characteristics of the mixed bicycle flow of electric bicycles with different ratios. The results show that when the density is low, the total speed of the hybrid bicycle flow containing electric bicycles is higher than the total speed of the pure bicycle flow [9]. Zhou et al. made an improved comparison between Nagel Schreckenberg (NS) CA model and multi-value CA (M-CA). It is proposed that the M-CA model shows more stable performance than the two-lane NS model, which is close to the result of real traffic [10]. Yu et al. compared the frequency of risk-taking behaviors of electric bicycle riders and set up a binary logit model to evaluate the impact of related factors [11].

2. Traffic flow characteristics of mixed non-motor vehicles

2.1. Investigation of mixed traffic flow

This survey chose to shoot during the morning peak (7:30-8:30) and evening peak (5:30-6:30) of working days (avoid choosing Monday morning peak and Friday evening peak). Obtain two hours of original video data, and select the time period suitable for the data according to the research needs. In the road section survey, the traffic flow in the morning and evening rush hours of four entrance lanes is selected as an example for illustration. For example, there are organic non-isolated facilities at the east entrance of Lianhua Street, and the road is smooth and straight. The intersections and traffic lights that should be avoided as far as possible when choosing the road section are about 20m away from the upstream intersection, and the flow reaching here tends to be stable.

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2.2. Investigation of traffic travel characteristics

The static data of a signalized intersection mainly includes information such as the type of intersection, the length of the crosswalk, the length of the channelization, and the design speed of the intersection.

2.2.1. Traffic data collection content

Considering the traffic characteristics of electric bicycles, including the speed change of electric bicycles when the green light is activated, the flow and density changes of non-motor vehicles including electric bicycles in the morning peak and evening peak hours, and the proportion of electric bicycles in the survey time period. The changing law of speed density, etc.The results of the investigation of the static conditions of the intersection are shown in Table 1, in which the non-motorized lanes are classified according to the non-motorized lane road grade and demand characteristics table 1. The results of the investigation of the static conditions at the intersection are shown in Table 1 and Figure 1.

Table 1: Static survey results of intersections

Category	Unit	East imports	West imports	North imports	South imports
Motorway Road Class	/	Trunk Road	Trunk Road	Trunk Road	Trunk Road
Design speed	Km/h	60	60	60	60
Single motor lane width	m	3.5	3.5	3.5	3.5
Number of motor vehicle lanes	/	3	3	5	2
Sidewalk width	m	5	5	5	5
Machine non-isolated type	/	Physical isolation	Physical isolation	Physical isolation	Scribe isolation
Non-motorized lane width	m	4.5	4.5	3.5	2.5
Non-motorized lane road grade	/	Main road	Main road	Secondary road	Secondary road

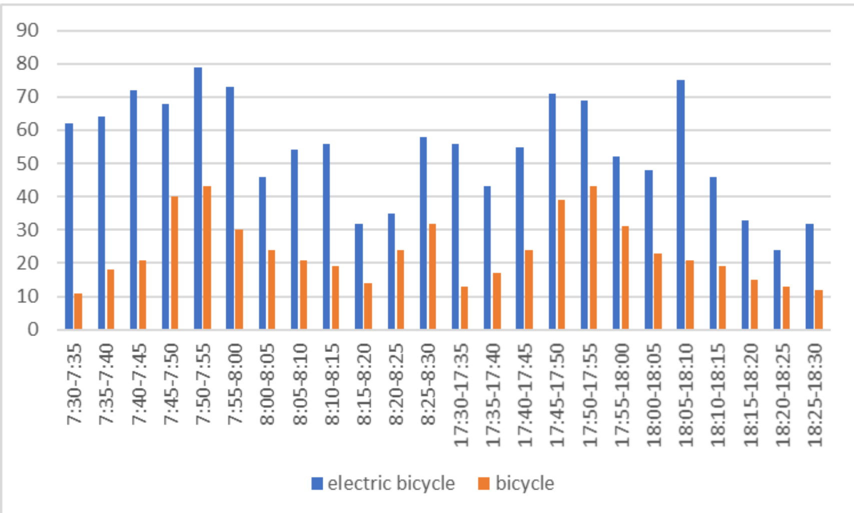

Figure 1: Electric bicycles and bicycle traffic distribution during peak hours

2.2.2. Rider characteristics analysis

The comparison of cyclist's choice of transportation, characteristics of electric bicycle and walking, human bicycle, public transportation and cars, as shown in Table 2.

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Table 2: Comparison and analysis of characteristics of electric bicycles and other vehicles

Category	bicycle	electric bicycle
Features	Manpower-driven, easy to maneuver, short-distance travel, a wider range of applications, male and female riding characteristics are different	Mainly driven by electricity, saving time and effort, long travel distance, strong adaptation to unfavorable terrain, small travel difference between men and women

In the survey of different types of non-motorized vehicles on various road sections near the intersection, the proportion of male trips and the proportion of different types of non-motorized vehicles were obtained. Men are choosing light-motorized electric vehicles. Cars and bicycles have an absolute advantage, reaching 68% and 60% on average. There are fewer options for electric bicycles. This may be related to the size and power of electric bicycles that are more suitable for female cyclists.

2.3. Average speed of mixed traffic flow

2.3.1. Spot speed

The location speed u is the speed when the vehicle passes a certain point on the road. The formula for location speed u is:

$$u = \frac{dx}{dt} = \lim_{t_2 - t_1} \frac{x_2 - x_1}{t_2 - t_1} \tag{1}$$

In the formula, x_2 and x_1 are the location points of the non-motorized vehicles at t_2 and t_1 respectively, which can be obtained by measuring the speed in a shorter distance section. Spot speed is usually used to set speed limits on roads [12]. The speed survey of this research is obtained by actual measurement with a speedometer. The average speed of electric bicycles was 24.58km/h, and the average speed of bicycles was 18.27km/h.

2.3.2. Density

Traffic density k represents the spatial density of vehicles, which refers to the number of vehicles existing per unit road length at a certain time. When non-motorized vehicles are driving on the road, because there are no strictly divided lanes, they exhibit swaying and the trajectory is in a serpentine shape. Moreover, the width of the non-motorized vehicle lanes of the survey sections is different, so the non-motorized vehicle traffic density used in this article is: Take the number of non-motorized vehicles per unit area of the non-motorized vehicle lane under saturation, and the unit is bike/m^2. The traffic density which can be formulated as shown in:

$$k = \frac{N}{LW} \tag{2}$$

Where N is the number of vehicles in the observation period, L is length of observation section, W is the width of the observation section (m), The density can only be obtained by the survey method along the length of the road section, which can be obtained by high-altitude photography or aerial photography. The average density of north imports is 0.416 bike/ m^2, the average density of east imports is 0.0894 bike/ m^2, the average density of south imports is 0.577 bike/ m^2, and the average density of west imports is 0.2878 bike/ m^2.

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3. Electric bicycle conversion factor

3.1. Saturation flow rate calculation and conversion factor of electric bicycle

Using the recorded video observation results, investigate the number of electric bicycles and bicycles passing the intersection stop line in a saturated state at the initial green light, and analyze the relationship between the proportion of different electric bicycles and bicycles and the saturation flow rate. The saturation state of the non-motorized vehicle flow continues Time is limited, and the statistical results of the saturation flow rate are directly affected by the statistical time interval, so the statistical time interval is increased by 2 seconds, separated from 4 to 24 seconds, and within each time interval, select the entire saturation time period The headway reached by more than 85% of the electric bicycles is the saturated headway of the observation period, and the reciprocal of the finally obtained headway is multiplied by 3600 to obtain the saturated flow rate[13].

$$S = \frac{3600}{h} \tag{3}$$

Where h is Saturated headway, unit s/bike, When investigating the saturation flow rate, choose electric bicycles and bicycles in a saturated state. At a certain section of the selected non-motorized lane, count the total number of non-motor vehicles, the number of bicycles, and the number of electric bicycles. Then calculate the number of electric bicycles and bicycles. The percentage of bicycles.

The following data is the average value of the saturated flow of each interval divided time period during the green light period of the signal period. The value of the saturated flow of non-motor vehicles on this road section ranges from 0.77bike/S·m to 0.93 bike/S·m , The average saturation flow rate is 0.86 bike /S·m.

Investigate the number of non-motorized vehicles passing through a certain section of the non-motorized vehicle lane at the beginning of the green period, collate the data and use the spss software to analyze the number of bicycles, the number of electric bicycles, and their respective proportions, and the total number of non-motor vehicles. The correlation between.

Through spss analysis, it can be intuitively obtained that the ratio of electric bicycles and the ratio of bicycles and the number of non-motor vehicles are respectively 0.422 and 0.534. The ratio of electric bicycles and the number of electric bicycles can be determined by R^2 of 0.936. The coefficient of determination is 0.945. Only when the coefficient of determination R^2 is larger, it indicates that the fitting effect of the model is better. The probability P value in the analysis of variance results is less than the significance level (0.05), and the average residual Durbin-Watson is 1.35. Therefore, the established model is statistically significant.

After comparison, this paper uses a linear regression equation between the number of single non-motor vehicles under saturation and the proportion of all non-motor vehicles to calculate the conversion coefficient of electric vehicles to bicycles. When non-motor vehicles are in saturation, When the proportion is close to 1, the number of non-motor vehicles is converted.

3.2. Calculation of conversion factor for electric bicycles

The vehicle conversion factor (PCE) refers to the process of mixed traffic flow on the road. When studying the characteristics of traffic flow, the hybrid vehicle is converted to a standard model for research. According to the relevant provisions of my country's Road Safety Law, electric bicycles and bicycles enjoy the same right of passage on urban non-motorized lanes. In order to facilitate the study of the characteristics of mixed traffic flow, here convert electric bicycles to standard bicycles and calculate the corresponding conversion coefficients.

There are 120 samples in this survey. Establish the linear regression equations of the number of electric bicycles and the ratio of electric bicycles, and the number of bicycles and the ratio of bicycles.

$$\begin{cases} y = 0.0149 z_1 + 0.1517 \\ R^2 = 0.9447 \end{cases} \tag{4}$$

When the ratio of bicycles is 1, the number of corresponding bicycles z_1 is 47.

The linear regression equation for bicycles

$$\begin{cases} y = 0.0223 z_2 + 0.0449 \\ R^2 = 0.99363 \end{cases} \tag{5}$$

When the ratio of electric bicycles is 1, the number of corresponding bicycles z_2 is 57, which can be obtained at this time. The conversion factor of electric bicycle to bicycle is

$$PCE_1 = \frac{Z_2}{Z_1} = 1.21 \tag{6}$$

3.3. Using space utilization efficiency to calculate conversion factor of electric bicycle

Considering that when non-motorized vehicles are driving fast, in order to ensure the safety of driving, they will randomly choose to overtake or change lanes. Therefore, non-motorized vehicles should also have a certain safe longitudinal clearance distance before and after. The measured data should be used to determine the effective driving area. As a basis, take the 85% quantile length of the bicycle's own width, the width 60cm, and the 85% quantile length 178 cm, the average bicycle speed is 11.03 km/h, and the braking deceleration is 3.25 m/s. The width of the electric bicycle is 85%, the width is 68cm. The length is 85%, the length is 189 cm, the average speed of the electric bicycle is 15.86 km/h, and the braking deceleration is 5.47 m/s. Other parameters take recommended values for reference. The effective driving length of the bicycle L_{ce}, the effective driving width W_{ce}.

$$\begin{gathered} L_{ce} = L_c + L_a + L_b \\ L_a = L_b = \frac{v_c \cdot t}{3.6} + \frac{{v_c}^2}{25.92 \cdot a} + l_0 \end{gathered} \tag{7}$$

Where L_c is 85% quantile length of bicycle, L_a is The longitudinal safe clearance distance of the following vehicle relative to the current bicycle, L_b is The current longitudinal safe clearance distance of the bicycle relative to the preceding vehicle, v_c is The measured average speed of the bicycle, namely 10.5km/h, t is the reaction time of the cyclist, generally between 0.5s and 1s, which is 0.7s, l_0 is The safe distance of bicycle driving is generally 0.5m or 1m.

$$\begin{gathered} W_{ce} = W_c + 2W_a \\ U_{ce} = L_{ce} \times W_{ce} \\ U_{ee} = L_{ee} \times W_{ee} \end{gathered} \tag{8}$$

Where L_c is 85% quantile length of bicycle w_c-85% width of bicycle, W_a is The horizontal clearance width for safe bicycle driving, take 0.25m. At this time, the space utilization rate for effective bicycle driving can be obtained. In the same way, the effective driving length L_{ee} of the bicycle, the effective driving width W_{ee}, and the space utilization rate of the effective driving can be obtained. Then through the saturation flow rate, the space utilization ratio between the bicycle and the electric bicycle is compared to obtain the conversion coefficient PCE2 of the electric bicycle relative to the bicycle.

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$$PCE_2 = \frac{U_{ee}}{U_{ce}} \tag{9}$$

Obtain the saturated flow rate of bicycles and electric bicycles during the observation period above, assuming that the conversion coefficient of electric bicycles to bicycles when the saturated flow rate is measured at one time, and then electric power is carried out for the east, west, south and north entrances at the intersection of Cedar Road and Lianhua Street. The vehicle conversion of bicycles gives the results shown Table 3.

Table 3: Conversion factor of electric bicycles for the four entrance lanes of the intersection

Category	Effective speed of e-bicycle v_e(km/h)	E-bicycle saturation flow rate S_e(pcu/s)	Efficient use of space for e-bicycles U_{ee}	Effective bicycle speed v_e (km/h)	Bicycle saturation flow rate S_c(pcu/s)	Efficient use of space for bicycles U_{ce}	PCE_2
1	15.42	8.85	182	10.42	6.76	191	1.254
2	15.84	8.21	176	10.87	6.31	186	1.231
3	15.79	7.61	178	1021	6.97	173	1.123
4	15.34	9.24	162	10.56	6.5	169	1.362

The conversion factor of electric bicycles to bicycles is set as the average value of the calculated PCE, which is 1.25. In summary, the conversion coefficient of electric bicycles to bicycles is 1.23 by taking the two methods.

4. Modeling of mixed traffic flow velocity-density relationship

According to the previous survey and the conversion of coefficients, the mixed non-motor vehicle traffic flow under different proportions is converted into the traffic flow of a single non-motor vehicle to facilitate the establishment of the model. When conducting the non-motor vehicle traffic volume survey, the electric bicycle The number is converted to the number of standard bicycles to conduct research on the operation of non-motorized traffic flow. The following formula (10) can be used to process the research data.

$$q = \frac{p_1 n_e + n_b}{T\omega} \tag{10}$$

Where q is flow rate (bike/h·m), p_1 is the conversion coefficient of electric bicycles relative to bicycles, which is calculated as 1.23 , n_e is the number of electric bicycles per unit of observation time, n_b is the number of bicycles per unit of observation time, T is unit observation time, ω is the width of the observation section.

According to the survey point data that has been obtained, the spss software is used for correlation analysis and regression analysis, and the most suitable speed-density model is found by fitting different models, as shown Figure 2.

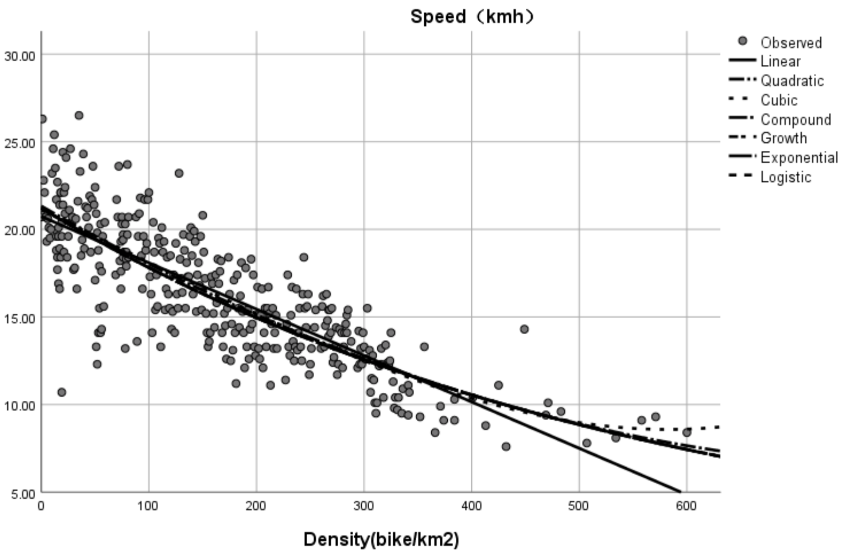

Figure 2: East imported non-motor vehicle speed-density map

Taking the east entrance road as an example, a density-speed regression model was established. The 350 groups of electric bicycle speed and density data obtained were analyzed by a scatter diagram. From the scatter diagram, you can intuitively see that in the case of low density, That is, when the road is not congested, the relationship between the speed and density of non-motorized vehicles can be divided into two categories. The first category is when the density of non-motorized vehicles is low, that is, the state of free flow, and the driving space is relatively sufficient. Motor vehicles have little influence on each other and can overtake at will. The speed of electric bicycles can reach a range of expected speeds, and the speed is basically not affected by the density of traffic. The second category is that the density of non-motor vehicles increases , The proportion of electric bicycles increases. At this time, it is in a state of non-free flow, and the driving space is limited. The mutual interference and friction between non-motor vehicle flows increase. The traffic flow starts to be like a motor vehicle flow, and the following vehicles show that they follow the preceding vehicle. The characteristics of the driving state, the speed of non-motor vehicles gradually decreases with the gradual increase of traffic density, with obvious curve characteristics.

The average density of non-motorized vehicles is 149.183 bikes/(km·m), the standard deviation is 136.2015, the average speed is 13.662km/h, the standard deviation is 5.9407, and the Pearson correlation is -0.737, at the level of 0.01 (single tail) , The correlation is significant. At the 0.01 level (one-tailed), the correlation is significant. In the nonparametric correlation test, the Kendall correlation coefficient and Spearman correlation coefficient are at the level of 0.01 (one-tailed), and the correlation is significant.

Through the regression analysis graph, model summary and parameter estimates, it can be seen that the composite function, the growth function, the exponential function and the logistic function have a coefficient of determination R^2 above 0.7, and the probability P values are all less than the significance level 0.005, indicating the fitting effect and significant The performance is good, and the model is statistically significant. Among them, the coefficient of determination R^2 of the growth function equation is 0.759, the F statistic is 745.480, and the fitting effect is the best, that is, the speed-density model of the eastern import is

$$\begin{cases} v = e^{2.928 - 0.003k} \\ R^2 = 0.759 \end{cases} \quad (11)$$

Similarly, get the regression fitting model of density and velocity in other directions , The results are shown in Table 4.

Table 4: Non-motor vehicle speed-density model

Entrance way	Width (m)	Regression equation	R^2
East	4.5	$v = e^{2.928 - 0.003k}$	0.759
West	4.5	$v = e^{1.356 - 1.482k}$	0.801
South	3.5	$v = -5.234\ln k + 23.16$	0.564
North	2.5	$v = 24.031k^{-0.342}$	0.671

5. Conclusion

Aiming at the current traffic phenomenon of mixed electric bicycles and traditional bicycles on urban non-motorized roads, the basic problems of traffic flow operation under this phenomenon are studied, and the intersection of Lianhua Street and Cedar Road in Zhengzhou City and the non-motorized roads of east, west, north and south are collected. Static and dynamic traffic data covers a wide range of non-motorized lane width values. The basic data collected mainly include: vehicle type, vehicle speed, cross-section flow, gender of cyclist, etc.

The basic characteristics of mixed non-motor vehicle traffic flow are analyzed, and the basic characteristics of mixed non-motor vehicle traffic flow are studied. The actual measurement data is used to analyze the impact of the statistical time interval of the data on the number of saturated vehicles; the speed-density relationship of mixed non-motor vehicle traffic is compared and analyzed. Using two methods of saturation flow rate and space utilization, the conversion coefficient of electric bicycles to traditional bicycles is calculated, and the accurate value of the conversion equivalent of electric bicycles to traditional bicycles is obtained, which is suitable for describing the exchange speed-density relationship of hybrid non-motor vehicles from a macro level. Mathematical model.

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