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SAMARKAND STATE UNIVERSITY NAMED AFTER SHAROF RASHIDOV

ILMIY AXBOROTNOMA

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MICROSCOPIC AND MACROSCOPIC FLOW MODELS OF TRAFFIC MANAGEMENT

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Abstract. Today, the issue of video data processing is very urgent. For example, determining the purpose of human behavior, analyzing economic networks, identifying and eliminating traffic jams on the streets, etc. Nowadays, the increase in the number of vehicles moving on the roads creates traffic jams on the city streets. This makes it urgent to eliminate traffic jams, especially in tourist cities. First of all, the causes of traffic congestion should be identified, traffic congestion can have various causes, such as insufficient capacity, unrestricted demand, traffic light delays, pedestrians crossing the roads at the wrong place, wrong location of sidewalks and etc. Therefore, there is a need to simulate and optimize traffic control to better meet this growing demand. In this research paper, microscopic and macroscopic traffic flow models are reviewed and their properties are discussed to determine which one is suitable for use in this study.

Key words: Microscopic flow models, Macroscopic flow models, Fixed-time control systems, Webster's Method, TRANSYT, SCOOT, SCATS, OPAC, MOVA.

Transport harakat boshqaruvining microskopik va makroskopik oqim modellari

Annotatsiya. Bugungi kunda video ma’lumotlarni qayta ishlash masalasi ancha dolzarb hisoblanadi. Masalan, inson hatti xarakati orqali maqsadini aniqlash, iqtisodiy tarmoqlarni tahlil qilish, ko‘chalarda yuzaga keladigan tirbandliklarni aniqlash va bartaraf etish va hakazolar. Hozirgi kunda yo‘llarda harakatlanayotgan texnikalar sonining ortib borishi shahar ko‘chalarida tirbandliklarni yuzaga keltirmoqda. Bu esa ayniqsa, sayyohlik shaharlarida yuzaga kelyotgan tirbandliklarni bartaraf etishni dolzarb qilib qo‘ymoqda. Birinchi navbatda tirbandlikning sabablari aniqlanishi kerak, yo‘l harakatida tirbandlikning turli sabablari bo‘lishi mumkin, masalan, yetarlicha sig‘im yo‘qligi, cheklanmagan talab, svetafor chiroqlarining kechikishi, piyodalarning yo‘llarni noto‘g‘ri joydan kesib o‘tishi, piyodalar yo‘laklarining noto‘g‘ri joylashganligi va hakazo. Shu sababli, ushbu ortib borayotgan talabni yaxshiroq qondirish uchun transport nazoratini simulyatsiya qilish va optimallashtirish zarurati tug‘iladi. Ushbu tadqiqot ishida mikroskopik va makroskopik transport oqimi modellari ko'rib chiqildi va ularning qaysi biri ushbu tadqiqotda foydalanishga mos kelishini aniqlash uchun ularning xususiyatlari muhokama qilindi.

Kalit so‘zlar: Mikroskopik oqim modellari, Makroskopik oqim modellari, Belgilangan vaqtli boshqaruv tizimlari, Webster usuli, TRANSYT, SCOOT, SCATS, OPAC, MOVA.

Микроскопические и макроскопические потоковые модели управления дорожным движением

Аннотация. На сегодняшний день вопрос обработки видеоданных очень актуален. Например, определение цели поведения человека, анализ экономических сетей, выявление и устранение пробок на улицах и т. д. В настоящее время увеличение количества транспортных средств, движущихся по дорогам, создает пробки на городских улицах. Это делает актуальным устранение пробок, особенно в туристических городах. В первую очередь следует выявить причины заторов на дорогах, заторы на дорогах могут иметь разные причины, такие как недостаточная пропускная способность, неограниченный спрос, опоздания на светофорах, переход пешеходами проезжей части в неположенном месте, неправильное расположение тротуаров и т. д.Следовательно, необходимо моделировать и оптимизировать управление дорожным движением, чтобы лучше удовлетворять этот растущий спрос. В этой исследовательской статье рассматриваются микроскопические и макроскопические модели транспортных потоков и обсуждаются их свойства, чтобы определить, какая из них подходит для использования в этом исследовании.

Ключевые слова: Микроскопические модели потока, макроскопические модели потока, системы управления с фиксированным временем, метод Вебстера, TRANSYT, SCOOT, SCATS, OPAC, MOVA.

1. **Introduction.** The increasing role of the city in the life of the society leads to a rapid increase in the population density and the concentration of traffic on the city streets. This, in turn, leads to an increase in traffic accidents, an increase in traffic jams, and air pollution due to smoke emitted from cars. Due to the limited infrastructure of the city, it is impossible to find an optimal solution based on a small amount of statistical data for the task of ensuring traffic-free movement of cars on the city streets. Currently, video surveillance systems are growing rapidly on city streets, which allows continuous monitoring of quantitative and qualitative traffic parameters and the use of vehicles as indicators of the transport system. Video cameras installed at traffic lights are most recognized for processing data in real time: low-precision calculation, classification of limited types of vehicles, determining the speed and direction of movement of all parts when crossing an intersection. allows you to solve the problem of tracking ect. But despite the advantages of developing such systems, there are not enough studies aimed at determining and analyzing the speed and movement of traffic flow by using cameras at intersections.

2. **Traffic flow model.** A traffic flow model is a mathematical description of traffic dynamics. It is used to analyze traffic incidents and ensure efficient traffic operations. The development of the flow model has been carried out for half a century, so there is a wide range of models. The level of detail (microscopic or macroscopic) is commonly used as a criterion for classifying traffic flow models [1]. In this research paper, microscopic and macroscopic traffic flow models are reviewed and their properties are discussed to determine which one is suitable for use in this study.

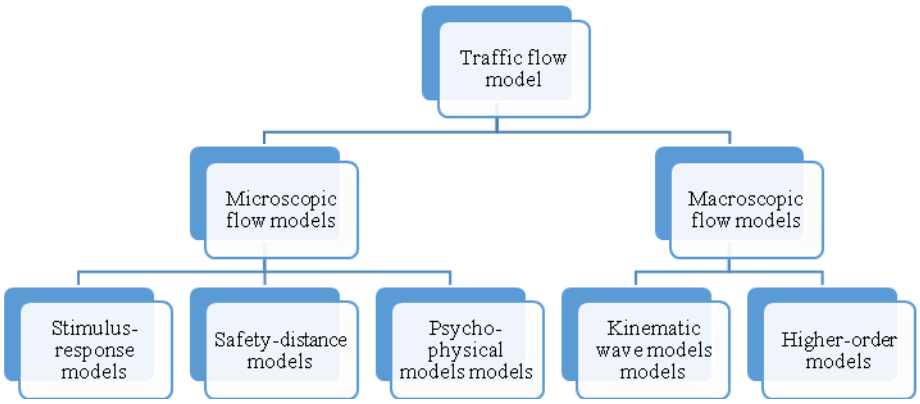


Diagram 1. Schematic view of the traffic flow model

2.1 Microscopic flow models. A microscopic traffic flow model takes into account the behavior of each individual vehicle, such as lane changes, acceleration, and the behavior of other drivers. Because the modeled vehicle in the flow model has a strong connection to the preceding vehicle, the microscopic flow model is also known as the vehicle-following model. Some of the main types of car following models are: the stimulus response model, the safety distance model, and the psycho-physical model. They are based on different assumptions of driving behavior.[2]

2.1.1 Stimulus-response models. The stimulus-response models describe the response of a driver as a product of a stimulus and the driver's sensitivity to the stimulus. A general form of the stimulusresponse model suggested by Chandler et al [14] is:

$$\alpha_{m+1}(t+1) = c_{\beta}[v_m(t) - v_{m+1}(t)] \qquad (1)$$

c_{β} is a sensitivity coefficient of vehicle m to the stimulus, which is the difference in speeds $v_m(t) - v_{m+1}(t)$ between the successive vehicles m and $m+1$. The acceleration (deceleration) α of the follower vehicle $m+1$ is a response to the stimulus. The response at a time step $t+1$ is calculated from the stimulus at time step t, since there is a time lag between the response and the stimulus. As the driver may become more sensitive to the stimulus when vehicles are close to each other, Gazis et al [15] modified (1) to:

$$\alpha_{m+1}(t+1) = \frac{c_\beta}{\chi_m - \chi_{m+1}}[v_m(t) - v_{m+1}(t)] \qquad (2)$$

The expression of the sensitivity becomes to $\frac{c_\beta}{\chi_m - \chi_{m+1}}$, which is affected by the distances between the successive vehicles m and $m+1$. (2) is subsequently generalised as:

$$\alpha_{m+1}(t+1) = \frac{c_\beta v_m(t+1)_l^c}{[\chi_m - \chi_{m+1}]_m^c}[v_m(t) - v_{m+1}(t)] \qquad (3)$$

(3) is known as the Gazis-Herman-Rothery (GHR) model [7], and the parameters c_l and c_m are calibrated with fields data in several studies, such as [8] and [9]. Although the stimulus-response model has been proposed since the late 1950s, it had been used less frequently until the mid-1990s due to the findings on the parameter values contradict with each other [16].

2.1.2 Safety-distance models. The second type of car-following models is the safety-distance model. Different from the stimulus-response model, a safety-distance model is based on the assumption that successive vehicles maintain a safe distance with each other to avoid collision. The early safety-distance model proposed by Pipe [20] expresses the location of two successive vehicle m and $m+1$ as:

$$\chi_m = \chi_{m+1} + d + l_m^{veh} + \tau v_{m+1} \qquad (4)$$

In Equation 2.4, d is the standstill distance between the vehicles, l^{veh} is the vehicle length and τv_{m+1} represents the travel distance. The travel distance is calculated as the product of the driver's reaction time τ and its travel speed v_{m+1} of the vehicle *m+1*. The whole part of $d + l_m^{veh} + \tau v_{m+1}$ forms the safe distance between the vehicles m and $m+1$. Comparing to the traffic data measured from field, the Pipe's model has less headway distance when vehicles travel at the speed close to minimum or maximum allowed speed [21]. Leutzbach [22] modifies the Pipe's model by introducing a breaking distance $\frac{v_{m+1}^2}{2\mu g}$, and the new expression is shown as:

$$\chi_m = \chi_{m+1} + d + l_m^{veh} + \tau v_{m+1} + \frac{v_{m+1}^2}{2\mu \dot{g}} \qquad (5)$$

where the μ is friction coefficient between vehicle and road surface and $\dot{g}$ stands for gravitational acceleration rate.

One development in the safety-distance model includes a time lag between the change in space headway with the front vehicle and the follower vehicle's reaction [19]. This model has been developed into a hybrid flow model [20] by combining with the LWR model.

2.1.3 Psycho-physical models

The psycho-physical model is another branch of the car-following models and are also known as the action point model. It is similiar to safety-distance model, but with a more detailed description on drivers' behaviour. In previous mentioned microscopic models, drivers strictly react to the headway change $\chi_m - \chi_{m+1}$ and relative speed change $v_m - v_{m+1}$ which are not the same in real life. A driver will not actively react to the front vehicle when the two vehicles are far apart. If the two vehicles are close to each other, the motion will be small for a driver to respond to changes in relative speed or headway so that the driver may not react as well. The first psycho-physical model is proposed by Wiedemann [3] and is the foundation of the widely used microscopic simulation software VISSIM [4]. In Wiedemann's model, perception thresholds are introduced (see Figure 2.1) to determine whether drivers will obey the car-following rules or not.

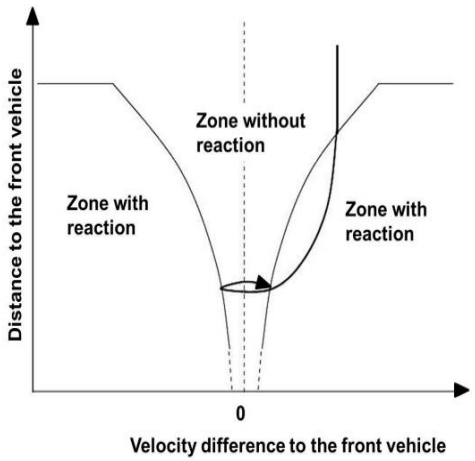


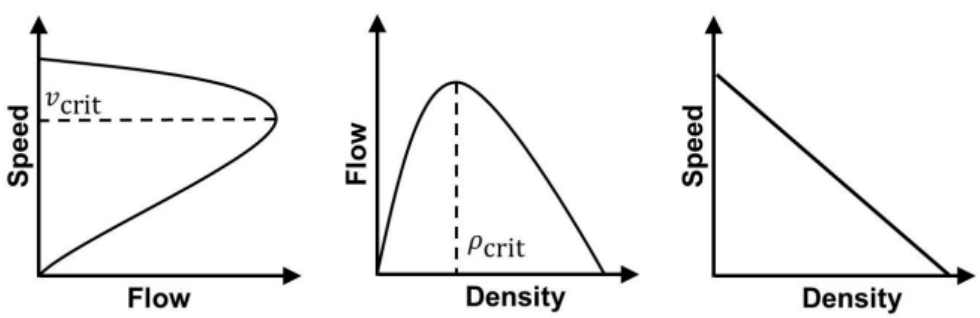
Figure 1: An example of perception threshold of the psycho-physical model (Source: Olstam and Tapani, 2004 [13])

2.2 Macroscopic flow models. A macroscopic traffic flow model is a mathematical traffic model that formulates relationships between traffic flow characteristics such as density, flow, average speed of traffic flow, etc. While the microscopic model is a space-time representation of individual vehicles, the macroscopic traffic flow model represents traffic as a continuous fluid. Before introducing the macroscopic models, a fundamental relation of traffic flow is discussed, which is the foundation of both the macroscopic and microscopic models. In this review of the macroscopic flow models, two types of model are introduced: kinematic wave model and higher-order model. The kinematic wave model is the first macroscopic model, and the higher-order model is the latest branch of the kinematic wave model which considers speed dynamics.

2.2.1 Fundamental relation of traffic flow. The development of the macroscopic model starts from the fundamental relations of traffic flow. Greenshields [17] first studies the fundamental relation of traffic flow and used three quantity terms (the density ρ, flow q and speed v) to describe the continuous traffic flow. The relationships among the three terms are known as fundamental diagrams (see Figure 2 as an example). The density ρ is defined as the number of vehicles at a unit length of a road, the flow q is defined as the number of vehicle passed in a unit of time and the speed v is the average speed of the traffic. The relation of the three terms can be expressed as:

$$q = \rho v \qquad (6)$$

In Figure 2, the speed and the density have a linear relationship, and a high-density traffic corresponds to a low moving speed. The relationship between the flow and the density is nonlinear, where a low flow rate corresponds two density status. Before the density reaches a critical value ρ_{crit},



the flow increases with the growth of density. When the density is higher than ρ_{crit}, the growth of density slows down the flow. Consequently, the relationship between the speed and the flow is also nonlinear. The fundamental relationships in Figure 2 are not unique, where various shapes of fundamental diagrams are proposed and can be found in [1,2,3,4,5].

Figure 2: Fundamental diagrams

2.2.2 Kinematic wave models

The first macroscopic flow model is proposed by Lighthill, Whitham and Richards [2, 11], which is known as the LWR model or kinematic wave model. The LWR model is a conservation law where no vehicle can be created or removed within a closed road section. Any changes in traffic (Δq and $\Delta\rho$) have to be the same during time interval Δt in the closed road section. The following expression is found for the conservation law:

$$\frac{\Delta\rho}{\Delta t}+\frac{\Delta q}{\Delta\chi}=0 \qquad (7)$$

$\Delta\chi$ is the length of the road section. When $\Delta\chi$ and Δt approach to 0, (7) converts to the general expression of the LWR model:

$$\frac{\partial\rho}{\partial t}+\frac{\partial q}{\partial\chi}=0 \qquad (8)$$

In order to solve the LWR model, several approaches have been proposed such as: Godunov method [10] and Cell Transmission Model (CTM) [18]. The CTM is one of the most popular methods, which dicretise each road into a collection of cells. According to the conservation law (8), the traffic density ρ of each cell i at time t can be expressed as:

$$\rho_c(t+1)=\rho_c(t)\frac{\Delta t}{l_c^{cell}}[q_{c-1}(t)-q_c(t)] \qquad (9)$$

where $q_c(t)$ is the outflow from cell c. Cell $c-1$ is the upstream cell, where traffic flows from cell $c-1$ into cell c. Δt is one time step and l_c^{cell} is the length of cell c. The step size Δt has to satisfy $\Delta t \le \min(\frac{l^{cell}}{v})$, which means the traffic can not travel more than one cell per time step.

CTM has a piecewise linear relationship with the traffic flow q and density ρ between each pair of successive cells (c, $c+1$). The maximum flow rate (saturation flow rate) for each cell is Q, and the maximum density (jam density) of each cell is ρ_{jam}. When there is no congestion, traffic moves through cells at a maximum speed (free flow speed). With the piecewise linear relationship, the outflow $q_c(t)$ from cell c to its downstream $c+1$ is determined as:

$$q_c(t)=\min\left\{v_c\rho_c(t), Q_c, Q_{c+1}, w_{c+1}, [\rho_{jam,c+1}-\rho_{c+1}(t)]\right\} \qquad (10)$$

where w is a shockwave speed which refers to the backward propagation speed of traffic. Equation (10) can be considered as an expression of the triangular flowdensity relationship. In addition, the effect of traffic signals is formulated as a binary variable at cell c:

$$Q_c(t)=\begin{Bmatrix} Q_c, & t\in G \\ 0, & t\in R \end{Bmatrix} \qquad (11)$$

G and R stand of the green and red phases. The setting of G and R use a timing plan derived from the signal control system.

The LWR model is sufficient to describe the basic flow dynamics such as formation and dissipation of traffic congestion. However, due to its simplicity, LWR has several issues such as the limitations in describing vehicle's speed dynamics and formulating the capacity drop phenomenon. The solution to address the dynamics of vehicle's speed is the higher-order model.

2.2.3 Higher-order models. Higher-order models are developed to overcome the limitation of the LWR model in mean speed dynamics. The LWR flow model contains one partial differential equation. Payne [13] proposed a second order flow model which contains the LWR's partial differential equation (conservation of vehicles) (8) and another partial differential equation to describe mean speed dynamics. In the Payne's model, the average speed of traffic on a road section is not only affected by the traffic density but also by the neighbour traffic conditions. The expression of mean speed dynamics in Payne's model is as follows:

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial \chi} = \frac{(v_{equal}(\rho) - v)}{c_l} + \frac{c_m^2 \partial \rho}{\rho \partial \chi} \qquad (12)$$

where $v_{equal}(\rho)$ is an equilibrium speed associated with density ρ. c_l and c_m are relaxation constant and anticipation constant respectively. The term $v\frac{\partial v}{\partial \chi}$ stands for the convection of traffic. Given a road section where vehicles are travel from its upstream road section, the average speeds of the two sections may not be the same. In this case, the vehicles have to accelerate or decelerate $\frac{\partial v}{\partial \chi}$ to adapt the traffic speed. In terms of the $\frac{(v_{equal}(\rho) - v)}{c_l}$, this is a relaxation term where the vehicles will try to reach the equilibrium speed v_{equal} of the road section. The last term $\frac{c_2^2 \partial \rho}{\rho \partial \chi}$ represents drivers' anticipation to their downstream road section. When the density ρ at the downstream road section is higher, the driver will anticipate to slow down.

A METANET [12] is a popular software used Payne's model for motorway modelling. It separates each road into a group of sections, and the length of each road section is l. Both fundamental relation of traffic flow (6) and conservation law (9) are considered. The mean speed dynamics of the METANET's model is as follows:

$$v_c(t+1) = v_c(t) + \frac{\Delta t}{\tau}[v_{equal,c}(\rho_c(t)) - v_c(t)] - \frac{\Delta t}{t} v_c(t)[v_{c-1}(t) - v_c(t)] - \\ - \frac{c_v \Delta t}{\pi l} \frac{\rho_{c+1}(t) - \rho_c(t)}{\rho_c(t) + c_k} \qquad (13)$$

The relaxation term $\frac{\Delta t}{\tau}[v_{equal,c}(\rho_c(t)) - v_c(t)]$ describes the behaviour of the drivers. Drivers will try to achieve the equilibrium speed $v_{equal,c}(\rho_c(t))$ of the road section. τ is the reaction time for drivers to realise the equilibrium speed of the road section, and when τ value is small the drivers can response quicker. The convection term $\frac{\Delta t}{t} v_c(t)[v_{c-1}(t) - v_c(t)]$ captures the impact of the driver's speed change from the upstream road section $c-1$. The last term $\frac{c_v \Delta t}{\pi l} \frac{\rho_{c+1}(t) - \rho_c(t)}{\rho_c(t) + c_k}$

is the anticipation term to consider drivers' speed change with respect to downstream road density. c_v and c_k are sensitivity parameters and they allow the model to be more sensitive to medium

or high density. The equilibrium mean speed in the relaxation term is derived from:

$$v_{equal,c}[(\rho_c(t))] = v_{f,c}\exp(-\frac{1}{c_\alpha}(\frac{\rho_c(t)}{\rho_{crit}})^{c_\alpha}) \qquad (14)$$

where $v_{f,c}$ is the free flow speed of road section c, c_α is a parameter which helps to form a non-linear fundamental relationship between the density and the mean speed.

Apart from the second order model, the higher order model can be further extended to a third order model proposed by Helbing [17]. The third order model introduces speed variance to take the chaotic feature of traffic into account.

Conclusion. We have presented the general structure of microscopic and macroscopic in the form of a diagram. In addition, we presented a general scheme of urban transport management systems. We have looked at the signal settings of the two coordinated traffic signals and the setup of separation, offset and cycle time settings. In the future research work, we will look at the estimation of road traffic and mathematical models using these models.

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