Dynamic Traffic Flow Entropy Calculation Based on Vehicle Spacing

Zupeng Liu¹,a, Caixia Xu²,b, Lingjuan Chen¹,c and Si Zhou¹,d

¹School of Automobile and Traffic Engineering, Wuhan University of Science and Technology, Wuhan 430081, China
²Hubei Posts and Telecommunications School, Wuhan 430079, China

a liuzupeng@wust.edu.cn b 13621818@qq.com c chenlingjuan@wust.edu.cn
d 1374835897@qq.com

Abstract. In information theory, entropy is a measure of uncertainty. The higher the degree of chaos in a system, the higher its entropy. The concept of entropy has also been applied to the evaluation of transportation systems. Because of the limitation of the existing traffic information collection technology, an entropy-based evaluation method has not been widely applied. With the development of on-board sensors and the Internet of vehicles, vehicle spacing information will be easier to acquire and transmit in real time; furthermore, traffic flow entropy will be calculated in real time. Based on the vehicle spacing on the road, the proportion of the distance between the vehicles was taken as the input data of the entropy calculation, and the summation result was normalised and corrected to obtain the calculation corresponding to the entropy and the degree of disorder. On this basis, the entropy values at different moments were repeatedly calculated, and the dynamic traffic flow entropy on the road segment was summarised. We constructed a one-lane road segment model in the simulation software, recorded the vehicle information, and calculated the dynamic traffic flow entropy. A comparison of the difference in the traffic flow entropy between different proportions of heavy goods vehicles revealed that a large proportion of the heavy goods vehicles corresponded to a large traffic flow entropy, indicating a large degree of disorder. The simulation results showed that the proposed method has good scientific value and is practical.

1. Introduction
The traffic system is a typical stochastic system, which uses macroscopic indicators such as flow, density, and speed to describe the characteristics of the traffic flow. However, under the same flow conditions, different vehicle arrival distributions correspond to different traffic flow operating conditions and to different levels of confusion. The orderly or disorderly traffic flow is an indicator that qualitatively describes the degree of chaos in traffic operations. Among them, order is relative to disorder; it is a rule state with a small degree of freedom. Therefore, it shows certainty and is thus predictable. Disorder refers to a disorderly system inside the system, that is, a state of motion that is completely irregular and has a large degree of freedom, randomness, and uncertainty [1].
With the development of intelligent connected vehicles, a new generation of smart cars with the Internet of vehicles and autonomous driving functions will gradually replace the traditional cars driven by humans. The intelligent connected car of the cluster will have certain self-organisation and self-coordination capabilities, and the traffic flow will be more regular and orderly. Domestic and foreign scholars have introduced the concept of information entropy into the study of traffic flow ordering metrics. Through the analysis of the relationship between the traffic distribution and the entropy principle, Da reveals the inherent meaning of traffic characteristics and uses the principle of entropy as the criterion for judging the distribution of traffic characteristics [2]. Li et al. applied a traffic entropy theory to propose a measure model of traffic flow disorder and analysed the disorder threshold of the actual road traffic flow [1]. Zhang proposed a traffic information recognition method based on entropy, which can not only quantitatively represent the distribution state of the vehicle but also estimate the traffic volume such as the average speed of the vehicle [3]. Liu et al. introduced the approximate entropy and statistical complexity feature quantities of nonlinear dynamics and calculated the approximate entropy and statistical complexity by calculating the time series data of five measured traffic flows [4]. Qiang et al. used the principle of entropy generation in thermodynamics to discuss the simple speed and density and the entropy generation caused by traffic pressure and viscous force. At the same time, the traffic management control was quantified as the negative entropy of governance, and the total entropy model of the traffic system was constructed. The traffic state discriminant entropy model provides quantitative data for traffic control [5–7]. Liu et al. constructed the thermodynamic entropy of a road traffic system, revealed the internal mechanism of the thermodynamic entropy generation of a traffic system, established the differential equation of the system state change by using the entropy theory, and provided a dissipative structure model [8, 9].

The commonly used entropy calculation methods are based on statistical data and cannot be applied to real-time entropy calculations. In this paper, a dynamic entropy calculation method based on vehicle spacing is proposed. Real-time entropy calculation can be realised in the Internet of vehicles environment, which can provide objective evaluation indicators for studying the cluster behaviour of intelligent networked vehicles.

2. concept of Entropy

Entropy is a state function in thermodynamics that was originally used to represent the ratio of heat to temperature absorbed by a substance in a reversible process. Furthermore, entropy reflects the disorder degree of a system. The larger the entropy value, the higher the disorder degree of the system [10].

In 1948, Shannon introduced the concept of entropy into information theory. Entropy is a probability-weighted statistical mean of self-information. Self-information and entropy are functions of probability and have nothing to do with the value of the variable. Entropy is a function of the probability distribution. The entropy of a system is equal to the sum of the entropies of its states. When the state probability of the system is equal, its entropy reaches a maximum. According to the definition and principle of entropy, the entropy of a discrete stochastic state can be expressed as follows:

\[
H = -\sum_{i=1}^{N} p_i \ln p_i
\] (1)

The entropy measurement models of traffic flow mainly include two types of thermodynamic methods and statistical physics.

The thermodynamic method refers to separately finding a quantity of extension and intensity, such as heat and temperature, and defining the entropy by the ratio of the two; for example, the density entropy of the traffic flow can be defined as an increase in the number of vehicles and the traffic, in other words, the ratio of density.

The classical statistical physics method uses the form of information entropy and generalised entropy to define entropy [10], and the calculation formula is as shown in equation (1). Taking traffic flow statistics as an example, the arrival distribution can be divided into a discrete distribution and a
continuous distribution. Different arrival distributions can calculate the entropy corresponding to the current distribution according to equation (1).

Under the same flow conditions, different arrival distributions calculate different entropy values, which characterise different traffic flow arrival characteristics. A special case is that the traffic flow arrives in a uniform distribution, and the calculated entropy value is the largest; another special case is that the traffic flow arrives at uniform intervals, uniform vehicle spacing, or a uniform headway distance, and the calculated entropy value is then very close to 0.

3. Calculation model of traffic flow entropy
Consider the one-lane road as the research object. The traffic flow is free to travel on the road section, and the randomly arrived vehicles form different vehicle spacings. Repeated calculations are performed at a small time interval, and the entropy value is obtained by collecting the entropy values of the traffic flow in the time series.

3.1. Statistical Entropy Model Based on Headway Spacing
At some point, the distribution of vehicle spacing in a platoon is as shown in Figure 1.

![Vehicle spacing distribution on the road.](image)

In Figure 1, assume that there are a total of \(N\) vehicles in the platoon, and the sum of all the vehicle spacings in the fleet is \(D\); that is, \(D = \Sigma d_i\). Let \(p_i\) be the ratio of each vehicle spacing; that is, \(p_i = d_i/D\). By substituting the defined \(p_i\) into equation (1), we can calculate the entropy value in terms of the statistical significance of the vehicle spacing.

3.2. Normalisation of Vehicle Spacing Entropy
According to the entropy value calculated using equation (1), when the number of vehicles \(N\) in the platoon is the same, the entropy values at different times are relatively comparable, and the degree of order and disorder of the different entropy values can be analysed. However, as the vehicle enters and leaves the road, the number of vehicles in the fleet changes dynamically. When the number of vehicles \(N\) in the platoon is different, the calculated entropy values are not comparable. In order to compare the entropy values corresponding to the number \(N\) of different vehicles, the calculation results are normalised on the basis of equation (1). Taking the entropy value of the formula (1) as the numerator, we consider the maximum entropy value corresponding to the number \(N\) of the vehicles as the denominator and calculate the relative entropy value as follows:

\[
H' = \frac{-\sum_{i=1}^{N} p_i \ln p_i}{\ln N}
\]  

The entropy value of the vehicle spacing calculated according to equation (2) is between 0 and 1. The entropy values of the vehicles with different vehicle numbers are comparable.

3.3. Correction of Meaning of Traffic flow Entropy
According to the concept and calculation method of information entropy, the larger the entropy value, the higher the disorder degree of the corresponding system. However, there is a negative correlation between the magnitude of the entropy calculated according to equation (2) and the degree of disorder;
that is, the more uniform the vehicle spacing in the fleet, the more orderly the corresponding traffic, and the larger the calculated $H'$.

In order to make the entropy value correspond to the degree of disorder, the calculation formula needs to be modified. As $H'$ is normalised, the entropy value can be exchanged by subtracting $H'$ from 1, and the negative sign in equation (2) can be shifted down and merged with the minus sign to form a plus sign. The corresponding calculation formula can be expressed as follows:

$$H'' = 1 + \frac{\sum_{i=1}^{N} p_i \ln p_i}{\ln N}$$  (3)

The entropy value calculated by equation (3) is consistent with the degree of disorder; that is, the larger the entropy value, the greater the disorder. When the team is driving on the road section, the vehicle spacing is relatively uniform, and the speed is relatively close, so the fleet is in an orderly state and the calculated $H''$ value is close to zero.

The above formula implies that the entropy calculation model only involves the vehicle spacing, but different vehicle speeds affect the dynamic traffic flow entropy. With the passage of time, the entropy value calculated by the traffic flow with a larger speed difference is larger.

4. Microscopic simulation test

We constructed a one-lane road segment model in VISSIM, loaded traffic on the road segment, and ran the simulation. The vehicle recording function of the simulation software was used to obtain the position information of all the vehicles each second. The entropy value of the traffic flow at that moment was counted in Excel, and the entropy value of the traffic flow at a plurality of times was summarised to obtain the dynamic vehicle entropy on the road segment.

In order to compare and analyse the influence of different vehicle composition on dynamic traffic flow entropy in the traffic flow, the proportion of heavy goods vehicles (HGV) in the traffic flow was increased from 2% to 17%. Comparing the entropy changes under the two schemes, we obtained the dynamic entropy of the traffic flow as shown in Fig. 2.

![Figure 2. Comparison of dynamic entropy values for different vehicle compositions.](image)

Fig. 2 shows that when the number of vehicles in the platoon changed, the entropy of the traffic flow had a large fluctuation. As shown by the high proportion of HGVs in the figure, there were 13 vehicles on the road at 165 s with the corresponding traffic entropy, and the entropy value was 0.236; then, the front car of the platoon left the road. At 166 s, there were 12 cars left and the entropy value was reduced to 0.160. This was attributed to the dynamic change in the platoon in the calculation.
model. When a car was added to the rear of the team, the sum of the vehicle distances of the team increased. Similarly, after the first car of the platoon’s head left the road, the vehicle spacing reduced. A comparison of the two curves in Fig. 2 revealed that the entropy value of a part of the time was larger when the proportion of the HGV was larger. In the time period of 155 s–165 s in the figure, the entropy values of the two were somewhat different. The small traffic flow entropy when the proportion of HGVs was small indicated that the traffic flow was more orderly.

In contrast, when the traffic volume on the road increased, the average of the traffic flow entropy changed. A comparison of the average entropy value under different flow rates is shown in Fig. 3.

![Figure 3](image)

**Figure 3.** Comparison of average entropy values under different flow conditions.

Fig. 3 shows that when the traffic volume increased from 800 veh/h to 1400 veh/h, the average entropy value decreased from 0.118 to 0.067, which was a large drop. This was because the vehicle spacing in the platoon tended to be relatively close due to the relatively large volume, which in turn implied that the traffic flow was relatively more orderly and the average entropy was smaller.

5. **conclusion**

The dynamic traffic flow entropy calculation method proposed in this paper can be applied to the traffic management and control of intelligent connected vehicles: the distance sensor is installed at the front of the vehicle, the distance between the vehicle and the preceding vehicle is obtained in real time, and the vehicle spacing information is sent to the roadside unit. The roadside unit on the road section collects all the vehicle spacing information and calculates the dynamic traffic flow entropy.

However, the calculation model proposed in this paper is based on one-lane roads. It does not consider multi-lane roads. In the future, it will be expanded from a single lane to multiple lanes and extended to the entire intersection. We also plan to propose evaluation indicators for signal control for intelligent connected vehicles.

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