Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2017, 4(4):137-142

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

A Qualitative Examination of the Composition of the Cooperative Vehicles

Çağlar Koşun[1], Çağatay Kök[2], Önder M. Tanriyapisi[3]*, Serhan Özdemir[3]

[1]Department of City and Regional Planning, Izmir Institute of Technology, 35430, Urla, İzmir, Turkey
[2]Department of Mechanical Engineering, Izmir Institute of Technology, 35430, Urla İzmir, Turkey
[3]Artificial Iytelligence and Design Laboratory, Department of Mechanical Engineering, Izmir Institute of Technology, 35430, Urla İzmir, Turkey

Abstract The compositions of the platoon of vehicles near an intersection are qualitatively investigated with respect to the extensive and nonextensive entropy approaches. A classification of the platoon memberships is presented to describe the character of the platoon. By this classification, master-slave relationship, semi-autonomous agents and peer-to-peer agents are discussed through three hypothetical traffic scenarios. In the initial setup of each scenario there are one platoon of vehicles and a fire truck where they could have different attitudes in the traffic flow. The traffic safety is the main concern in the study, and the clearance fluctuations of the vehicles and their compositions in the platoon are examined in the entropy framework. Two forms of entropies *i.e.* extensivity and nonextensivity are taken into consideration. The perfect control and rigid body of the platoon i.e. zero or near zero fluctuations in clearance are explained with the extensive entropy, whereas large fluctuations in clearance would be characterized by the nonextensive entropy framework. In the first scenario, the rigid body of the platoon is kept through the route and the platoon is governed by a master all along. In the other scenarios, the rigid body of the platoon disappears and the successive clearance fluctuations would be large since the fire truck and individual vehicles are highly influential in the traffic. This also leads to the division of the vehicular platoon into two parts and the emergence of the different vehicular compositions.

Keywords Traffic flow, vehicular platoon, nonextensivity, clearance, composition

1. Introduction

Many particle systems could be investigated in a wide variety of disciplines. Particles such as robots, animals and vehicles would represent the elements of these systems and they could exhibit a number compositions. The occurrence of the compositions would stem from many factors e.g. cooperation, leader dominion and emergency. In this study, the compositions of the vehicles are examined in a traffic flow context. Our main assumption is that the vehicles have a cooperative moving in a platoon formation, and according to the given scenarios their compositions could change. This change is related to two different entropic approaches in this study. First, the classification of the platoon membership is presented and then three scenario-based vehicular compositions are arranged and qualitatively examined through the given entropic approaches.

There are a number of studies on the control and connections of cooperative vehicles in literature. For example, Ahmane *et al.* [1] propose a new control approach for the traffic of cooperative vehicles at the isolated intersection and their model depends on Timed Petri Nets with Multipliers. The control strategy in the paper is evaluated through simulations of the vehicles and the results are discussed. Guler *et al.* [3] propose an intersection traffic control algorithm in their study. Two objective functions *i.e.* minimizing delay and minimizing number of stops are utilized for the defined algorithm. Minimizing delay algorithm is also compared with the first-in-first-out control algorithm and fixed time traffic signal strategy, then the evaluation of the values of the autonomous vehicle control and the connected vehicle technology is given. In another recent work

[2], a game-theory-based traffic control algorithm for uncontrolled intersections is proposed. Of the literature of fluctuations on the traffic variables, for example, Wagner [9] analyzes the fluctuations in a car following context, and focuses on the headway and speed variables. The results from single-vehicle stationary detector data and trajectory data are investigated in the study. In the study [10], the effects of the headway changes with memory on the car following behavior is examined with the measured data. The improved car following model is proposed and the simulations are carried out in regard to single lane roadway with a traffic light. The studies [6, 11] would be also typical examples for the connected vehicles and intersection management.

The contribution of this paper is to qualitatively investigate the composition of platoon of vehicles near the intersection based on the extensive and nonextensive entropy frameworks under the classification of the platoon memberships. Hence, the three scenarios involving an unsignalized intersection with the platoon of cars and a fire truck are illustrated and the compositions of the vehicles and inter-vehicle clearance fluctuations of the platoon are discussed. The motivation behind this study is based on the recently proposed Kosun–Ozdemir platoon interval. In the study [4], the authors propose the upper and lower limit of Tsallis q index for vehicular platoon formation with respect to clearance fluctuations. According to the methodology used in the study, the extensive (Boltzmann-Gibbs) thermostatistics would be relevant to expound the perfectly controlled and rigid body platoon, while nonextensive (Tsallis) one would be pertinent to the dynamics of the conspicuous clearance fluctuations. The reader may investigate the quantitative aspects of the clearance error data of the given platoon flow in [4]. Moreover, in view of the lane-changing behaviors of the individual vehicles in terms of both the extensive and nonextensive entropies, the study [5] would be the relevant one.

2. Method

The scenario-based compositions of the platoon of vehicles are discussed in terms of extensive and nonextensive statistical mechanics in this study. The main properties of these two approaches are given as follows.

2.1. Extensive (Boltzmann-Gibbs) statistical mechanics

Let us consider a collection of particles in a container. Each particle has own velocity and position, and those correspond to states in the system. The particles would choose the states to adjust their compositions. In Boltzmann-Gibbs (BG) statistical mechanics, the movement of those particles would match e.g. the short-range interactions and Markovian memory, and the formulation of BG entropy is given below.

$$S_{BG} = -k \sum_{i=1}^{W} P_i \ln P_i \quad (1)$$

where W is the total number of configurations, pi is the probability, and k is Boltzmann constant.

Some features of BG statistical mechanics could be listed as below [8]

- Short-range interactions: In the light of these interactions, the property of the system entropy would be additive. The short-range interactions among the elements of the system correspond to the nearest neighborhood or close distance interactions.
- Markovian memory: The memory is short in a given dynamic process. The short memory of a system does not deal with all of the past states and the range is close.
- Ergodicity: To satisfy the ergodic property both the time average and ensemble average are equal to one another so that their statistical identities match each other.
- Strong Chaos: In strong chaos, there is at least one Lyapunov exponent which is greater than zero. Also, when chaotic systems are getting stronger, their correlation dimensions will get larger.

2.2. Nonextensive (Tsallis) statistical mechanics

Tsallis proposed the possible generalization (nonextensive thermostatistics) of BG thermostatistics in 1988 [7]. According to the nonextensive approach, all the properties of real systems may not be simplified and governed by the conditions of BG thermostatistics. The q entropic index, which covers BG approach, is introduced in the nonextensive entropy formulation. To deeply explain the system dynamics, the nonextensive framework could be a convenient tool for the analyses of the given phenomenon.

The formulation of the Tsallis entropy is given below.

$$S_q = k\frac{1-\sum_{i=1}^{W} P_i^q}{q-1} \qquad \left(\sum_{i=1}^{W} P_i^q = 1; k > 0\right) \tag{2}$$

where q is the entropic index

In comparison with the BG statistical mechanics, some features of nonextensivity would be such as long-range interactions, non-Markovian memory, q-Gaussian distributions, nonergodicity, and weak chaos[8].

3. The Compositions of Vehicles and Discussion

As previously mentioned, particles in a traffic flow system could be represented with vehicles, and their behaviors and compositions may be described in multitude ways. In this study, the qualitative characteristics of the vehicles in the traffic are discussed within the entropy framework. The compositions of the vehicles could be determined by the certain rules. These rules could be, for example, driving with safe distance and conformity in the traffic flow. Hence, the compositions of the vehicles would stem from the interactions among them. In this study, these interactions are considered as short-range and long-range to evaluate the compositions of the platoon of vehicles. As explained before, short and long-range interactions are linked with the extensive and nonextensive entropy frameworks, respectively.

3.1. Classification of platoon memberships

In order to provide the character of the platoon of the cooperative vehicles, three membership descriptions are given. Thus, the platoon memberships are classified as master-slave relationship, semiautonomous agents and peer-to-peer agents in this study. Please consider their descriptions given below.

Master-Slave Relationship: In a multiple vehicle platoon formation, there is one master and the rest of the platoon corresponds to slaves. All the slave agents (vehicles) are assumed to be dependent to the master vehicle (leading vehicle). In the master-slave relationship, the vehicles are well-coordinated and the platoon behaves like a rigid body system. The interactions are assumed to be short-range or nearest neighbor.

Semi-autonomous agents: In the platoon formation, the vehicles could be designated semi-autonomous because they could behave independently from the leading vehicle under certain conditions. These conditions are ascribed to the state of emergency in traffic in this study. Except the emergency, the behavior of the agents of the semi-autonomous class matches the master-slave one. In semiautonomous driving, the rigidity of the platoon could be broken, and hence the platoon would be divided two or more parts. This could be stemmed from the long-range interactions occurring in traffic flow.

Peer-to-peer agents: In the peer-to-peer agents formation in the platoon, all the vehicles are able to determine their own positions/speeds in the traffic to satisfy the platoon and highway traffic safety. In order to maintain safe traffic, platoon agents (vehicles) may either decelerate or accelerate. In this classification, drivers are always wary, and the long-range interactions govern the platoon.

3.2. Scenario Formulation

In this section, the classification of platoon memberships is explained through three hypothetical scenarios considering the entropic approaches. The scenarios are depicted with the car platoon and fire truck on the four-leg intersection from Fig. 2 to Fig 4. The initial positions of the platoon and fire truck are given on Fig 1. Thus, it is supposed that the vehicles in each scenario begin to move at this initial position.

Let us consider that a platoon of highly-controlled and cooperative vehicles approaches the intersection where vehicle clearance fluctuations are almost constant and only small fluctuations in clearance between the vehicles occur. At the same time, a fire truck also moves to the same intersection from the crossing road (Fig 1). The behaviors and compositions of the vehicles in the platoon are examined in the scenarios. Overtaking is not allowed in the scenarios. The memberships i.e. master-slave relationship, semi-autonomous agents and peer-to-peer agents are independently evaluated in the scenarios 1, 2 and 3, respectively.

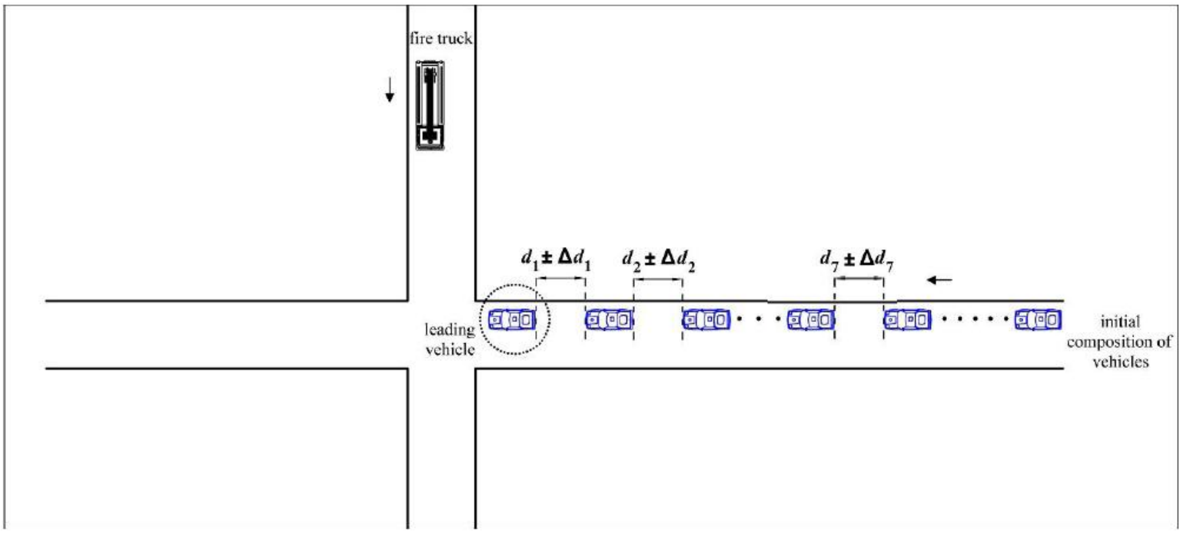

Figure 1: Initial positions of a platoon of vehicles and fire truck on the highway

For the scenario 1 (Fig. 2), it is seen in the initial positions that the platoon of vehicles is much closer to the intersection and the fire truck approaches without wailing siren. The leading vehicle of the platoon acts as master and passes the intersection prior to the arrival of the fire truck. The rest (slaves) in the platoon follows the master with the constant clearance fluctuations. To avoid a possible collision, the fire truck also stops at the intersection and waits the passing of the platoon. The rigid body of the platoon is kept and the platoon is governed by the master all along. This perfectly controlled vehicular formation in terms of clearance fluctuations would be characterized by Boltzmann-Gibbs entropic domain.

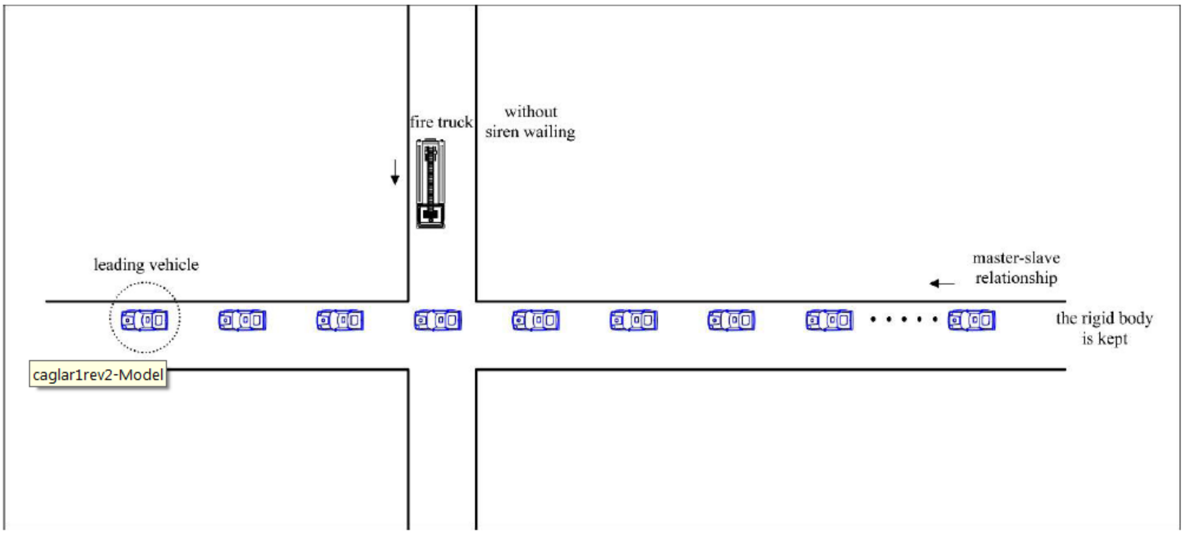

Figure 2: Master-Slave Relationship

In the scenario 2 (Fig. 3), while the platoon is passing at the intersection, the fire truck starts to wail siren nearby the intersection. Drivers of the platoon, who are semi-autonomous, perceive the emergency, and thus stop at the intersection not to block the route of the fire truck. The clearance fluctuations change between the vehicles approaching the intersection and they have many degrees of freedom now due to the emergency i.e. blockage of the highway. This leads to the disappearance of the rigid structure (initial cooperation) of the platoon. Hence, the second (new) platoon and its own leading vehicle emerge. The following drivers perceiving the behavior of the new leading vehicle drop their speed within the long-range distance. Nonextensivity would be the underlying thermostatistics to account for the position choices of the vehicles, and the clearance fluctuations of the new vehicular composition in the traffic.

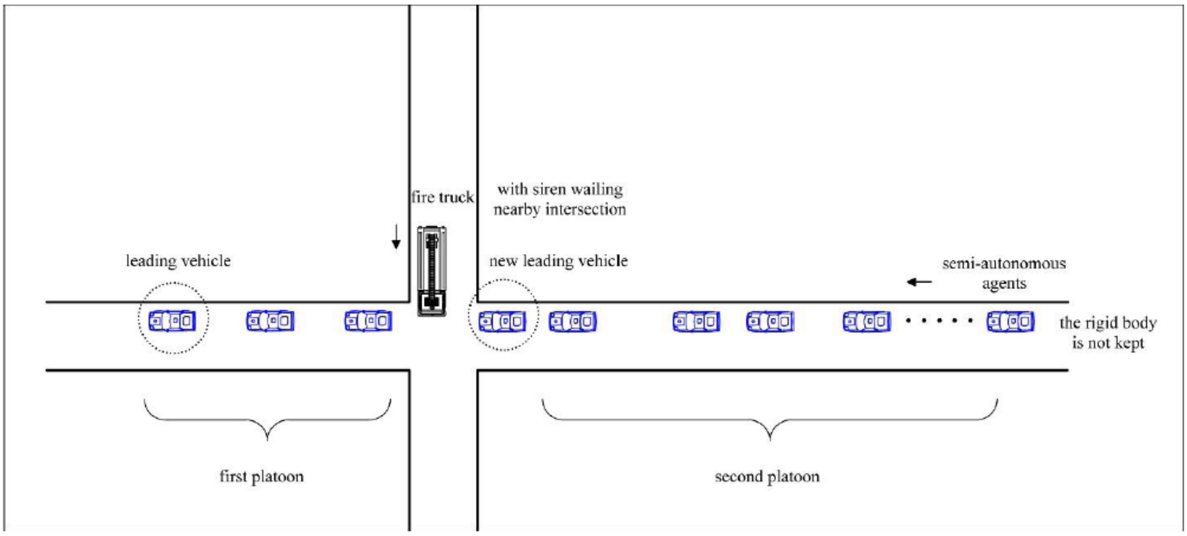

Figure 3: Semi-autonomous agents

In the scenario 3 (Fig 4), the fire truck moves with siren wailing through the highway and all the vehicles in the platoon observe the fire truck in advance. Some of the vehicles in the platoon cross the intersection with safe conditions, whereas the others decelerate and do not cross since the fire truck takes the priority over the vehicles. Now, the fluctuations in clearance between the successive vehicles would not be stable. The rigid structure of the platoon is not kept and the second platoon composition emerges as well. In Scenario 2, the emergency commencing nearby the intersection is the key factor i.e. it appears instantly, whereas in scenario 3 the emergency is recognized by all the drivers in the platoon beforehand. The long-range interactions could affect the behavior of the drivers, and incorporate the entropy into the nonextensivity domain.

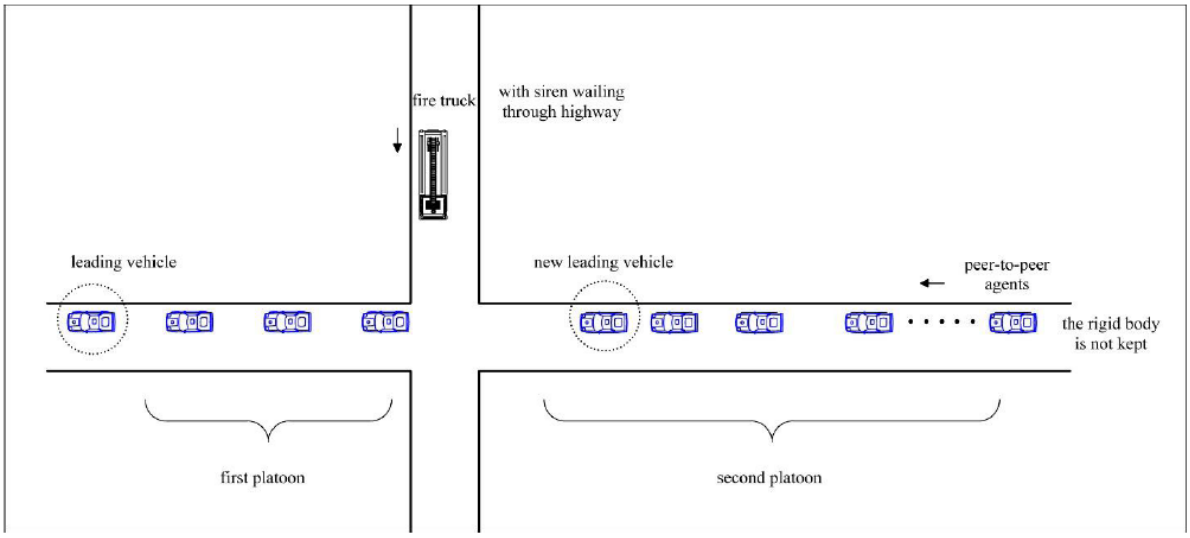

Figure 4: Peer-to-peer agents

In these scenarios, the authors focus on the relationship between the classification of the platoon memberships and the compositions of the vehicles. Two forms of the entropy are considered and the safety of the platoon of the vehicles and fire truck is treated. Hence, the scenarios are simplified and formed avoiding possible collisions in the traffic.

4. Conclusions

In this study, three memberships for the traffic flow are defined and the compositions of the platoon of vehicles are investigated through these memberships near the intersection. Three hypothetical traffic flow cases are presented, and the extensive and nonextensive thermostatistics are considered to explain the vehicular compositions and clearance fluctuations in the platoon. In the study, the conservation of the rigid body of the platoon would match the extensive (BG) entropy approach where the fluctuations in clearance between vehicles are zero or near zero. Once the perfect control of the platoon begins to disappear, the nonextensive entropy approach is the relevant one to expound the vehicular platoon flow. In such a scenario, inter-vehicle clearance fluctuations would not be kept constant. One may investigate the limiting cases in terms of clearance fluctuations of the platoon formation in the study [4]. In a further research, the compositions of other cooperative many-particle systems might be examined through short and long-range interactions by considering the two entropies.

References

[1]. Ahmane, M., Abbas-Turki, A., Perronnet, F., Wu, J., El Moudni, A., Buisson, J., & Zeo, R. (2013). Modeling and Controlling an Isolated Urban Intersection Based on Cooperative Vehicles. Transportation Research Part C: Emerging Technologies, 28: 44-62.
[2]. Elhenawy, M., Elbery, A. A., Hassan, A. A., & Rakha, H. A. (2015). An Intersection Game-Theory-Based Traffic Control Algorithm in a Connected Vehicle Environment. In Intelligent Transportation Systems (ITSC), 2015 IEEE 18th International Conference, 343-347.
[3]. Guler, S. I., Menendez, M., & Meier, L. (2014). Using Connected Vehicle Technology to Improve the Efficiency of Intersections. Transportation Research Part C: Emerging Technologies, 46: 121-131.
[4]. Kosun, C., & Ozdemir, S. (2017). Determining the Complexity of Multi-Component Conformal Systems: A Platoon-Based Approach. Physica A, 471: 688-695.
[5]. Kosun, C., & Ozdemir, S. (2017). An Entropy-Based Analysis of Lane Changing Behavior: An Interactive Approach. Traffic Injury Prevention, 18(4): 441-447.
[6]. Lee, J., & Park, B. (2012). Development and Evaluation of a Cooperative Vehicle Intersection Control Algorithm under the Connected Vehicles Environment. IEEE Transactions on Intelligent Transportation Systems, 13(1): 81-90.
[7]. Tsallis, C. (1988). Possible Generalization of Boltzmann-Gibbs Statistics. Journal of Statistical Physics, 52(1-2): 479-487.
[8]. Tsallis, C. (2011). Entropy: A Unifying Path for Understanding Complexity in Natural, Artificial and Social Systems. Information, Knowledge, Systems Management, 10(1): 291-311.
[9]. Wagner, P. (2012). Analyzing Fluctuations in Car-Following. Transportation Research Part B: Methodological, 46(10): 1384-1392.
[10]. Yu, S. & Shi, Z. (2015). An Improved Car-Following Model Considering Headway Changes with Memory, Physica A, 421: 1-14.
[11]. Zohdy, I. H., & Rakha, H. A. (2016). Intersection Management via Vehicle Connectivity: The Intersection Cooperative Adaptive Cruise Control System Concept. Journal of Intelligent Transportation Systems, 20(1): 17-32.