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Social dilemma structure hidden behind traffic flow with route selection

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HIGHLIGHTS

- We developed a cellular automaton model for realistic traffic flows to explore the social dilemma.
- We found a Chicken-type dilemma occurring in traffic flow with giving travel time as information.
- This social dilemma can be solved if the appropriate traffic information is provided.

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ABSTRACT

Several traffic flows contain social dilemma structures. Herein, we explored a route-selection problem using a cellular automaton simulation dovetailed with evolutionary game theory. In our model, two classes of driver-agents coexist: D agents (defective strategy), which refer to traffic information for route selection to move fast, and C agents (cooperative strategy), which are insensitive to information and less inclined to move fast. Although no evidence suggests that the social dilemma structure in low density causes vehicles to move freely and that in high density causes traffic jams, we found a structure that corresponds to an n-person (multiplayer) Chicken (n-Chicken) game if the provided traffic information is inappropriate. If appropriate traffic information is given to the agents, the n-Chicken game can be solved. The information delivered to vehicles is crucial for easing the social dilemma due to urban traffic congestion when developing technologies to support the intelligent transportation system (ITS).

1. Introduction

Motivated by the growing social concern regarding traffic, previous studies have investigated the traffic model [1–5]. Traffic flow can be interpreted as a self-driven multi-particle system. Among traffic models such as the kinetic theory of gases [6], the fluid-dynamical model [7], and car-following model [8], the cellular automaton (CA) model [9] has been intensely investigated owing to its flexibility and expandability. After considering whether each model can successfully reproduce real traffic flows, maximizing the traffic flux in an urban setting is of interest. Therefore, we can investigate the downstream flow, supported by sophisticated devices based on the intelligent transportation system (ITS), which contributes to improving traffic efficiency relative to the usual flow [10].

Although there have been pioneer studies (e.g. Ref. [11]) dealing with generalized traffic flow of agents that are analyzed from game theoretic viewpoint, almost no previous studies than ours [12–15] on the decision-making processes of vehicle-drivers affect traffic flows have been reported. If the traffic flow results from the competition for a finite resource (“road”)

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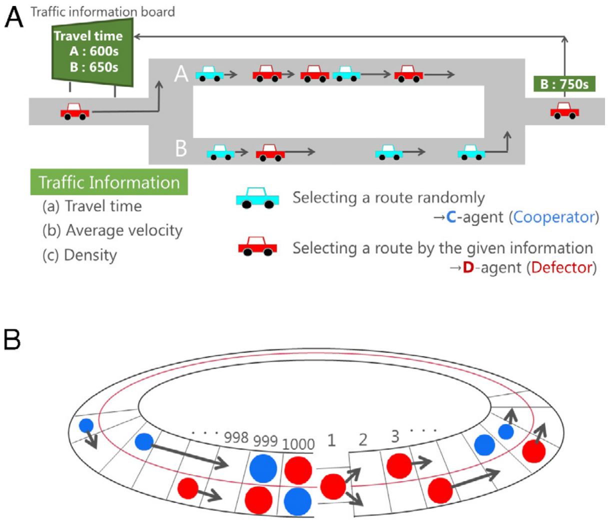

Fig. 1. Panel (A); Model for route selection where the vehicle agents, cooperator and defector coexist, wherein both select their next route randomly or by referring to the given traffic information of either (a) travel time, (b) average velocity or (c) density. Panel (B) shows the present CA model for panel (A), where the red and blue circles indicate defectors and cooperators, respectively. The two lanes separated by the red line mean that vehicles are not allowed to change lanes in the cells (labeled with #2 to #1000). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

among many drivers who are seeking shorter and more comfortable driving times, then whether the social dilemma originates from the intentions of drivers should be investigated. The class of dilemma such as the Prisoner's Dilemma (PD) game or Chicken (Snow Drift) game is hidden beneath the observed traffic flow under various traffic conditions, which is controlled by traffic density. We detected that several social dilemma structures, which are represented by n-person (multiplayer) Prisoner's Dilemma (n-PD) games, appear in certain traffic-flow phases caused by the closure of a lane [12,13]. We confirmed that an n-PD game structure appears in the high-density phase area, but social dilemma does not exist in the free-flow and jam phases. We also investigated whether lane-changing behavior introduced by inconsiderate drivers incurs a social dilemma in multilane traffic. We found that the social dilemma of n-PD games [14] can be enhanced if a more dangerous maneuver such as rapid lane-changing is taken by such drivers [15]. Several studies addressing dilemmas in traffic flow have been reported [16,17].

In this paper, we present another social dilemma behind traffic flow than what we have reported so far. Meanwhile, the route-selection problem has been extensively studied [18,19], wherein one study involves the modeling of route selection motivated by the application of ITS. A driver is exposed to route selection where he/she must choose a two-fold path reaching the same destination with the same distance. A driver can use traffic information, which may be provided through either the vehicle information and communication system (VICS) device or a simple signage board. The traffic information that can increase traffic flux to maximize the social efficiency is important. Herein, we investigate whether a social dilemma exists in a particular traffic flow; if so, we determine its dilemma class and whether it belongs to the PD, Chicken, or other games. Our previous studies [12–15] concerned on microscopic behaviors by drivers like lane-changing, perhaps taking place every moment, while the present study focuses on rather driver's macroscopic decision, which is a situation of route-selection that takes place at a certain point and a certain moment in driving course.

The remainder of the paper is organized as follows. Section 2 describes our model and the simulation procedures, Section 3 presents and discusses the results, and Section 4 summarizes our findings.

2. Model setup

Our model is based on Xiang's model [19]. We assume that a traffic system has two routes A and B.[1] Each route is of the same length $L = 1000$ and a single lane. We split the road at the entrance and converge them at the exit. The terms "entrance" and "exit" are trivial because the system is cyclic, as shown in Fig. 1.

At the branching point, a vehicle is given traffic information. We defined two types of agents. One is the defector (D agent), who always moves fast and takes routes with least travel time, largest average velocity, and least average density. Another agent is the cooperator (C agent), who is less interested in moving fast and randomly chooses a route.

[1] Although we have not shown and discussed the case of three alternative routes, we confirmed that the general conclusion can be drawn is basically same as the case of two alternative routes, as reported herein.