Fuel Loss and Jams due to Pausing Railroad Crossings

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In Japan, all cars must pause before crossing the railroad for avoiding the accidents. This rule was established by a law in 1960. In fact, however, railroad crossings come to the serious bottlenecks because of this pausing rule and this bottleneck causes heavy jams. In this study, by using cellular automaton model we have investigated the traffic flow at railroad crossings in two cases: with pausing and without pausing. Moreover, the lost time due to pausing at railroad crossings have been also quantitatively estimated by both numerical simulations and analytical calculations. As the results, we have found that these estimations are good agreement with the data by actual measurements.

I. INTRODUCTION

In recent years, many kinds of environmental efforts have been made all over the world. One of the important challenges to prevent the environmental pollution is to reduce the traffic jams, since traffic jams make cars idle away and unwanted exhaust gas are emitted. In this study, we focus on the traffic flow at railroad crossings. In Japan, all cars must pause before crossing the railroad for avoiding the accidents. This rule was established by a law in 1960, since, at that time, the accuracy of crossing gates is insufficient. However, nowadays, the crossing gates have been grown in performance and the mechanical errors are more or less on naught. In order to abolishing the pausing rule, we contribute in terms of mathematical theory of "Jammology".

This paper is organized as follows, in Sec. 2 the surveys on railroad crossings are reported. In Sec. 3, one of the major traffic model, which is described as the stochastic cellular automaton model, is improved and applied to one-dimensional road where the railroad crossing are included. The results of numerical simulations and analytical calculations about traffic flow and lost time are shown in Sec. 4, and conclusions are given in Sec. 5.

II. SURVEYS ON RAILROAD CROSSINGS

TAB. I shows the number of top three accidents at railroad crossings. The leading case of railroad accidents is that cars are stuck on the railroad. This kind of accidents is actually caused by engine stall due to pausing and accounts for about half of the total number of accidents. Note that, the accidents due to neglect of pausing rule do not happen.

According to Japanese law, it is admitted as a special case that cars do not need to pause at the railroad crossing with traffic signal, when crossing gates are open and traffic signal is green. However, we have never seen that the signal is red and gate is open. From comparative table (TAB. II), there is no difference between the traffic signals and the crossing gates. Thus, it would not be an exaggeration to say that these plants result in the wasteful overlapping investment.

Accident Cases	Number
Be stuck by closed crossing gates	105
Ignore closed crossing gates	61
At railroad crossings without a security alarm	29

TABLE I: The number of accidents about the top three

Traffic Light	Green	Yellow	Red
Railroad Crossing	Open	Alarm	Close

TABLE II: Comparative table between traffic signals and railroad crossing

In terms of traffic flow, abolishing the pausing rule leads to removing the bottleneck and doubling the traffic flow, which has major economic effects (two hundred billion yen) as well as the idea of Electronic Toll Collection (ETC) System. In terms of environmental conservation, the amount of oil consumption is reduced by 510 thousand kilo liter per year and environmental burdens are also reduced by 1.18 million ton per year. For all of these reasons, abolishing the pausing rule becomes excellent amendment for resolving jams, energy saving, environmental pollution and reducing accidents.

However, it is an undeniable fact that we have some misgivings about abolishing the pausing rule. One of the possible accidents is that cars may be left at a railroad as seen in an intersection. Cars often enter into the intersection though the front road is bumpy and cars strand in the intersection. If a similar phenomenon is happened at the railroad, this situation leads to the horrible accidents. One possibility for avoiding this kind of accident is painting a road indication, where cars must not stopping and standing. Actually, this indication is used in front of a fire station or police station, since an emergency vehicle can rush immediately to the site without blockage in front of the station.

III. RAILROAD CROSSING MODEL BASED ON M-SOV MODEL

In this section, we explain the modified stochastic optimal velocity (m-SOV) model, which is improved the established stochastic optimal velocity (SOV) model[1], and apply this m-SOV to the traffic model at railroad crossing. One of the advantages of SOV model is that the two significant stochastic models, which are the asymmetric simple exclusion process (ASEP)[2] and the zero range process (ZRP)[3], are reduced in the limit of low or high sensitivity of drivers. These two stochastic models are quite useful to calculate analytically, since they are exactly solvable in the sense that the probability distribution in the steady state can exactly calculated.

In SOV model, it is possible that a car stops even if the front cell is empty. This phenomenon occurs from stochastic behavior of model (not intentionally) and the car keeps its current velocity. In contrast, it is naturally possible that a car stops if the front cell is not empty. This phenomenon occurs from physical behavior (intentionally), but a car keeps its current velocity as well as the stochastic stop. That is, in SOV model, if a car stops at any time step, its velocity does not change to 0 until the car stay the same place for a long time, since those two situations of stopping are treated exactly the same. In fact, however, those two situations are entirely different. Thus, we suggest modified SOV model by discriminating the case that a car stops *stochastically (not intentionally)* from the case that a car stops *physically (intentionally)*. If next cell is not empty and a car stops, its velocity change to 0, since the stop is treated as *intentional*. In contrast, if next cell is empty, a car stops *not intentionally* and its velocity is treated the same way as the SOV model. Thus, we decide its velocity equals to 0 only if a car stops *physically (intentionally)*(TAB. III).

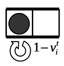
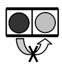
	Stochastically Stop 	Physically Stop 
SOV model	In both cases, the velocity is updated by $v_i^{t+1} = (1-a)v_i^t + aV_{opt}(\Delta x_i^t)$. (†)	
M-SOV model	The velocity is updated by (†).	The velocity is updated by $v_i^{t+1} = 0$

TABLE III: Comparative table of velocity update between SOV model and m-SOV model.

Let us imagine that the road partitioned into L identical cells such that each cell can accommodate at most one car at a time, and we set the number of cars equals to M. 3 cells at the center of the one dimensional road are set down as the area of railroad crossing, where cars can not stop (FIG. 1). Moreover, we impose periodic boundary conditions and adopt *parallel update*. In these simulations, we set that 1 cell corresponds to 6 meters and 1 time step corresponds to 0.72 seconds, since the mean velocity in city traffic is about 30 kilometers per hour and mean headway distance is about 6 meters.

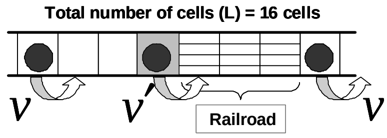


FIG. 1: Schematic view of the CA model with railroad crossing.

For comparison of traffic flow, we consider two situations: one situation is that cars must pause in front of the railroad crossing (at the shaded cell in FIG. 1) and another situation is that cars can enter into the railroad crossing without pausing.

- *With pausing*
  In this case, cars must pause in front of the railroad crossing, even if the cell over the railroad is empty. The velocity is updated by

$$v_i^{t+1} = \begin{cases} 0 & \text{(pausing and physically stopping)} \\ (1-a)v_i^t + aV_{\rm opt}(x_{i+1}^t - x_i^t) & \text{(otherwise)}. \end{cases} \tag{1}$$

- *Without pausing*
  In this case, cars do not need to pause in front of the railroad crossing. The velocity is updated by

$$v_i^{t+1} = \begin{cases} 0 & \text{(only physically stopping)} \\ (1-a)v_i^t + aV_{\rm opt}(x_{i+1}^t - x_i^t) & \text{(otherwise)}. \end{cases} \tag{2}$$

IV. SIMULATION RESULTS AND ANALYTICAL CALCULATIONS

The typical space-time plots of railroad crossing simulations are given by FIG. 2. From this figure, we have found that the jam at the bottleneck is resolved by abolishing the pausing rule.

FIG.3 shows the flow-density plots, so-called *the fundamental diagram*. This figure demonstrates that the traffic capacity (the maximum value of traffic flow) without

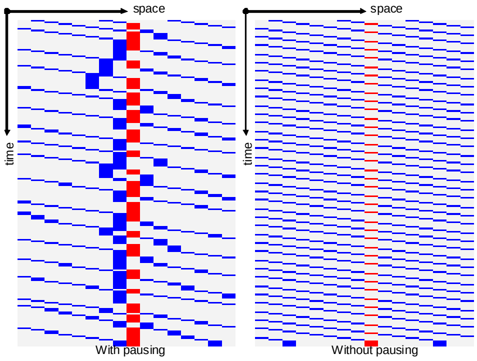


FIG. 2: Space-time plots for parameter values ($M = 3, L = 16$, (about 100 meters), $a = 0.1$, $0 \leq$time≤ 200). In the case with pausing, cars must pause at the center (red) cell.

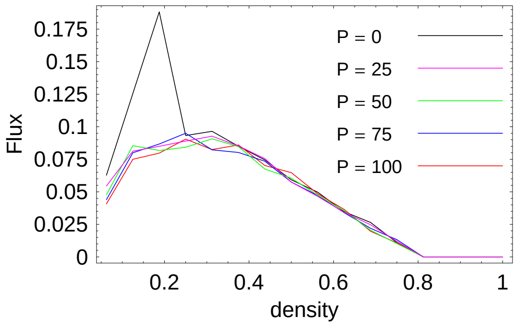


FIG. 3: The fundamental diagram for parameter values ($L = 16, a = 0.1$). The symbol P is used to denote the rate of cars of pausing. For example, $P = 50$ corresponds to the case that a half of cars pauses at the railroad crossing.

pausing ($P = 0$) becomes about twice as large as the capacity with pausing ($P \neq 0$) around $\rho = 0.2$, where ρ is the density of cars. However, since the flow except $P = 0$ is quite similar, we have found that the flow hardly changes, until all car do not pause at the railroad crossing.

In FIG. 4, we plot the difference of lap-time between with pausing and without pausing. It is found that the time difference at low density equals to about 9.5 time steps regardless of the system size. Moreover, the time difference of all cases reaches the maximum value at around critical density ($\rho \sim 0.2$).

Now, we have estimated the time difference analytically at the low density. At the low density we can assume that the headway distance of each cars is significantly large, i.e. we put $V_{opt}(\Delta x_i^{t-1}) = 1$. Furthermore, we also put $v_i^0 = 0$ as the initial condition, since our aim is to estimate the lost time due to pausing. Under these assumptions, velocity updating formula (($\dagger$) in TAB. III) is reduced to

$$v_i^{t+1} = (1-a)v_i^t + a. \tag{3}$$

By solving this recurrence formula with initial condition

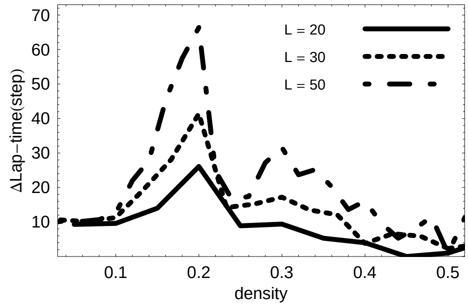


FIG. 4: The plots of the time difference between with pausing and without pausing for the parameter $a = 0.1$.

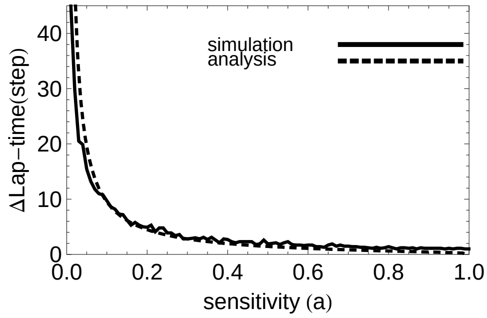


FIG. 5: The time difference plots of computer simulations and analytical calculations for the parameter $M = 1$.

($v_i^0 = 0$), we obtain

$$v_i^t = 1 - (1-a)^t. \tag{4}$$

Since this formula can be regarded as the cumulative distribution function, the probability density function is

$$\frac{\partial v_i^t}{\partial t} = -(1-a)^t \log(1-a). \tag{5}$$

Hence, the expectation value of time ($T(a)$) is

$$\begin{aligned} T(a) &= \int_0^\infty t \frac{\partial v_i^t}{\partial t} dt \\ &= -\frac{1}{\log(1-a)}. \end{aligned} \tag{6}$$

As long as the density is low, we have reasonably good agreement between the analytical calculations (6) and the corresponding numerical data obtained from computer simulations (see FIG. 5). For example, in the case $a = 0.1$, we get the estimates $T(0.1) = 9.49122$ from analytical calculations. The corresponding number obtained from direct computer simulations is 9.5, which is shown at the low density limit in FIG. 4.

V. CONCLUSIONS

Japanese law obliges that cars must pause in front of the railroad crossing before enter into the railroad and this pausing rule causes heavy jams by bottleneck effect. In order to estimate the impact of pausing rule on traffic flow, we have first improved the SOV model and suggested the modified SOV model by discriminating two stopping behavior of cars : *stochastically* and *physically*. Next, we have applied this m-SOV model to the traffic model at railroad crossing and compare the traffic flow with pausing to the flow without pausing. As the results, we have found that the traffic flow without pausing becomes about twice as large as the flow with pausing around the critical density. In particular, we have found that the flow hardly changes, until all car do not pause at the railroad crossing. Moreover, the lost time due to pausing is estimated by both computer simulations and analytical calculations and we have obtained the lost time is about 9.5 steps (about 6.8 seconds).

[1] M.Kanai, K.Nishinari and T.Tokihiro, Phys. Rev. E **72**, 035102 (2005)

[2] B. Derrida, E. Domany, and D. Mukamel, J. Stat. Phys. **69**, 667 (1992).

[3] F. Spitzer, Adv. Math. **5**, 246 (1970).