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SMART CITY AS AN ALTERNATIVE SOLUTION FOR URBAN DEVELOPMENT AND EQUITY IN INDONESIA

- ***Talkshow Smart Education***
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ADIWIDYA 9 | #SINERGIKANPERAN
KAMIL PASCASARJANA ITB

Traffic Scofflaw and Electronic Ticket Effectiveness Model

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Abstract. Electronic ticket is one smart city establishment effort in Indonesia. However, a not effective electronic ticket could affect driver behaviour in obeying the traffic law. This paper presented a dynamic system model of traffic scofflaw with the effectiveness of electronic ticket. Futhermore, two numerical simulation presented to give an illustration and recommendation about traffic scofflaw amount in long term.

1. Introduction

Technology integration is a foundation in building a smart city and electronic ticket is, probably, one of the most well-known concept in building a smart city. As written on [1], electronic ticket was an innovation to realizes public service with technology based. However, some study like [2] wrote that in some place, electronic ticket still didn't give much effect in supressing the traffic scofflaw number.

Traffic violation happened because of some factors, such as lack of law enforcement and people tend to follow other people habit [2]. The unsupressed traffic scofflaw number could indicate that electronic ticket implementation was still not effective. However, how much the uneffective electronic ticket will affect that scofflaw habit?

Model in this paper was made to analyze and predict the number of traffic scofflaw using two factors as described above. As an illustration of long-term effect, two numerical simulations result also given.

2. Model Formulation

Traffic Sofflaw and Electronic Ticket Effectiveness is based from SIR model that was introduced by William Kermack and Anderson Mckendrick in 1927 [3]. With some modification, Traffic Scofflaw and Electronic Effectiveness Model divided driver into four compartments, which are:

a) S: sucpetible driver that could violate the law,
b) I: traffic scofflaw who were not exposed by camera,
c) C: traffic scofflaw who were exposed by camera,
d) R: driver who will not violate the law.

Moreover, some assumptions that were used in this model are:

a) growth and decrease rate of every compartement was considered same,
b) every S driver who interacted with C driver will be I driver or R driver,
c) every I driver who was exposed with camera will be C driver. If I driver interacted with C driver, there is a chance for them to be R driver,
d) C driver who were caught and fined will be R driver.

With those assumptions, transmission diagram of the model could be formulated as figure 1. The formulated system equation also presented on equation (2.1)

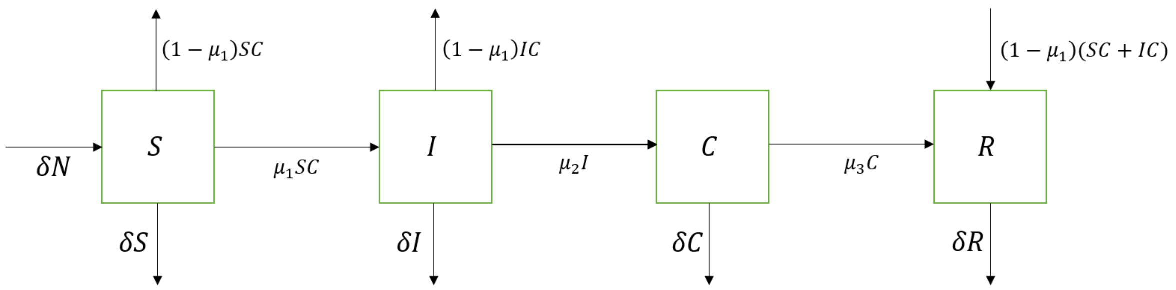

Figure 1. Traffic Scofflaw and Electronic Ticket Effectiveness Transmission Diagram

$$\begin{cases} F_1 = \frac{\partial S}{\partial t} = \delta N - \mu_1 \frac{SC}{N} - (1-\mu_1)\frac{SC}{N} - \delta S \\ F_2 = \frac{\partial I}{\partial t} = \mu_1 \frac{SC}{N} - (1-\mu_1)\frac{IC}{N} - \mu_2 I - \delta I \\ F_3 = \frac{\partial C}{\partial t} = \mu_2 I - \mu_3 C - \delta C \\ F_4 = \frac{\partial R}{\partial t} = \mu_3 C + (1-\mu_1)\frac{(SC+IC)}{N} - \delta R \end{cases} \tag{2.1}$$

where N is total of drivers, δ is growth and decrease rate of driver, μ_1 is probability of driver to be scofflaw or not after interacting with C driver, μ_2 is rate of scofflaw exposed by camera, and μ_3 is rate of caught and fined scofflaw.

3. Stability Analysis of the Model

Study about human criminal activity with dynamic system has been studied like in [4] and [5]. On their paper, Mcmillon and Chaharborj presume the basic reproduction number (R_0) in epidomilogy mathematics as growth rate of criminal spread. We will tend it similarly. To avoid confusion, free-violation term in this paper will be analogous with free-disease on epidomiology mathematics and R_0 will be analogous with violation spread (we will still use R_0 as notation). Traffic scofflaw will be eradicated if $R_0 < 1$.

In general, there are two stability on dynamic system model that could be analyzed, which are the stability of free-violation and the stability of not free-violation. However, the stability of not free-violation calculation was long and hideous and we decided to not analyze it.

We will use Jacobi method and Next Generation Matrix to find the free-violation stability and R_0. The detail of used method can be found on [5] which used same method.

The Jacobi Matrix from system equation (2.1) defined as

$$J = \begin{bmatrix} \frac{\partial F_1}{\partial S} & \frac{\partial F_1}{\partial I} & \frac{\partial F_1}{\partial C} & \frac{\partial F_1}{\partial R} \\ \frac{\partial F_2}{\partial S} & \frac{\partial F_2}{\partial I} & \frac{\partial F_2}{\partial C} & \frac{\partial F_2}{\partial R} \\ \frac{\partial F_3}{\partial S} & \frac{\partial F_3}{\partial I} & \frac{\partial F_3}{\partial C} & \frac{\partial F_3}{\partial R} \\ \frac{\partial F_4}{\partial S} & \frac{\partial F_4}{\partial I} & \frac{\partial F_4}{\partial C} & \frac{\partial F_4}{\partial R} \end{bmatrix} \tag{2.2}$$

Let $F_1 = F_2 = F_3 = F_4 = 0$, then the free-violation equillibrium point is

$$(S, I, C, R) = (N, 0, 0, 0) \tag{2.3}$$

Substitute the values from (2.3) to (2.2), then we will found the characteristic value of J, which are

$$\lambda_1 = \lambda_2 = -\delta$$
$$\lambda_3 = \lambda_4 = \frac{-2\delta - \mu_2 - \mu_3 + \sqrt{4\mu_1\mu_2 + \mu_2^2 - 2\mu_2\mu_3 + \mu_3^2}}{2}$$

Assume every parameter lay on real set interval $[0, 1]$. Obviously $\lambda_1, \lambda_2 < 0$. Furthermore, let $\lambda_3, \lambda_4 < 0$, then it should satisfy

$$\sqrt{4\mu_1\mu_2 + \mu_2^2 - 2\mu_2\mu_3 + \mu_3^2} < 2\delta + \mu_2 + \mu_3 \tag{2.4}$$

with $2\mu_2\mu_3 < 4\mu_1\mu_2 + \mu_2^2 + \mu_3^2$. Properties (2.4) will make the system stable on free-violation point.

Let I and C as violator compartment, then we will have

$$\mathcal{F} = \begin{bmatrix} 0 & \frac{\mu_1 S}{N} \\ \mu_2 & 0 \end{bmatrix}, V = \begin{bmatrix} -\frac{(1-\mu_1)C}{N} & -\frac{(1-mu_1)I}{N} \\ 0 & -\mu_3 - \delta \end{bmatrix}$$

such that,

$$F = \mathcal{F}V^{-1} = \begin{bmatrix} 0 & -\frac{\mu_1 S}{N(\mu_3 + \delta)} \\ \frac{\mu_2 N}{C\mu_1 - \delta N - \mu_2 N - C} & \frac{\mu_2(-1 + \mu_1)I}{(C\mu_1 - \delta N - \mu_2 N - C)(\mu_3 + \delta)} \end{bmatrix} \tag{2.5}$$

Finding spectral radius of (2.5), we will have

$$R_0 = \sqrt{\left(\frac{\delta^2\mu_1\mu_2 + \delta\mu_1\mu_2^2 + \delta\mu_1\mu_2\mu_3 + \mu_1\mu_2^2\mu_3}{(\delta^2 + \delta\mu_2 + \delta\mu_3 + \mu_2\mu_3)^2}\right)} \tag{2.6}$$

4. Numerical Simulation

Numerical simulation is given to give an illustration of the work above. The parameter value is displayed as in table 1.

Table 1. Parameter value

Parameter	First value	Second value
N	1000	1000
δ	0.20	0.20
μ_1	0.20	0.01
μ_2	0.90	0.90
μ_3	0.90	0.90

Let $S(0) = 800, I(0) = 200, C(0) = R(0)$. From table 1, we will have graphic simulation of the dynamic system for violator compartment as below.

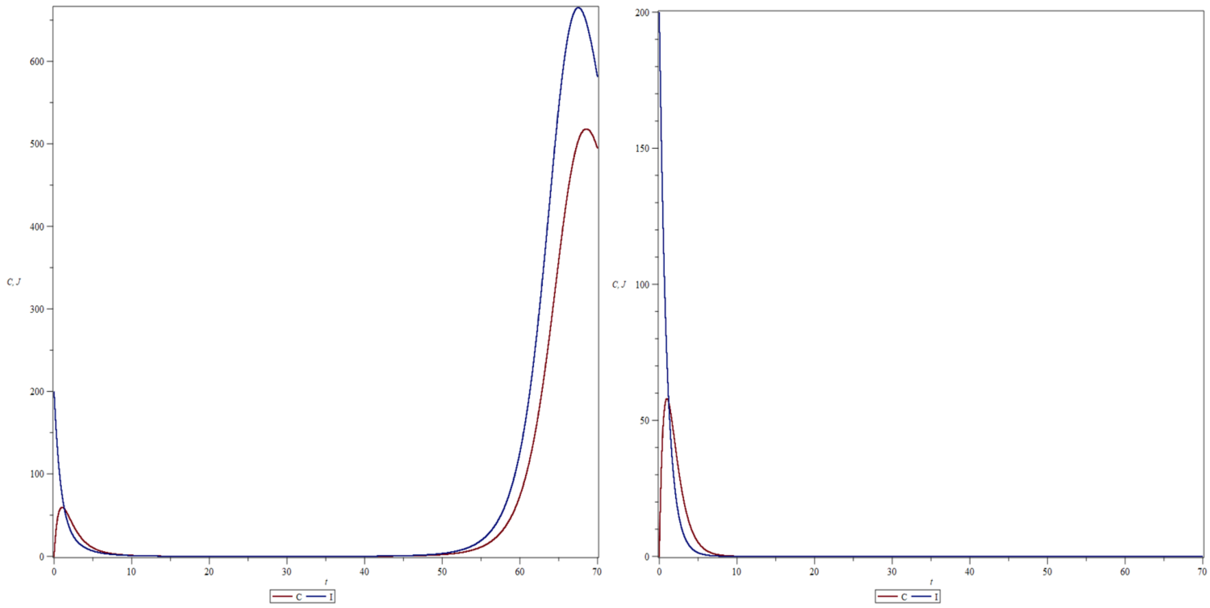

Figure 2. Numerical simulation of model with $\mu_1 = 0.2$ (left) and $\mu_1 = 0.01$ (right)

From Figure 2, traffic scofflaw will not be eradicated when $\mu_1 = 0.2$. This is because the system was unstable with the given value, which, in this case, lead to increasing scofflaw for even next $70t$ with unit time t. However, the violation will be eradicated when $\mu_1 = 0.01$, that could indicate that the effectiveness of electronic ticket is very influental to supress the traffic scofflaw number.

5. Discussion

Traffic Scofflaw and Electronic Ticket Effectiveness model had been given. Some properties and R_0 also had been given to show how to supress the traffic scofflaw number. Futhermore, the numerical simulation tend to indicate that the effectiveness of electronic ticket is very influental to supress the traffic scofflaw number. It's best to assume that enforcement of electronic ticket establishment should be taken seriously to reduce the violator number or else it will not give any benefit at all.

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