

# *Estimating the Effect of Idling Stops on Energy Saving and Carbon Reduction at Signalized Intersection*

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**Abstract:** *Responding to the issues of global warming and climate change, this research developed a procedure to estimate the effect of idling stops on red light at signalized intersection under random arrival of vehicles. Two kinds of models, one for estimating the maximum idling stop time and another for estimating the practical idling stop time, were at first proposed. The estimated idling stop time could then be converted into fuel consumed, and the corresponding CO<sub>2</sub> emissions based on the results of numerous tests, studies and investigations. The results of a case study on one approach at a specified intersection in Taipei city show that the idling stops of motorcycles during the morning peak period on holidays can save about 206 l fuel consumed per year, and reduce about 930 kg CO<sub>2</sub> emissions correspondingly. If the evaluation base extends to all approaches, and even to all intersections, the effect of idling stops would be remarkable and significant.*

**Keywords:** *idling stops; idling stop time; fuel consumed; CO<sub>2</sub> emissions*

## 1. INTRODUCTION

Aiming at the issues of global warming and climate change, many strategies and measures can be applied to reduce the greenhouse gases. Idling stops, defined as turning off vehicle engine due to temporal parking, waiting on red light, or stopping by traffic jam [1], could be regarded as one of the most effective ones for this purpose. Although the advantage of idling stops has not yet been proven de facto, it can be expected and estimated in advance. Obviously, the effect of idling stops heavily depends on the number of idling stops triggered by the vehicle drivers, and the duration of individual idling stops, based on which the idling stop time (IST) is accumulated. Since some relationship exists between the IST and fuel consumed, the effect of idling stops on energy saving and carbon reduction can be estimated through conversion functions as long as the IST can be determined. In this research, we hence initiated estimation models to determine the IST, and then converted it further into fuel consumed and the corresponding CO<sub>2</sub> reduction to explore the potential effect of idling stops.

Two kinds of models were proposed to estimate the IST at signalized intersections under random arrival of vehicles. The first one was used for the maximum IST under the ideal condition whereas the second one was applied to the practical IST by taking account of the psychological needs of individual drivers in the real life. Moreover, the arrival pattern determines the vehicle arrival time at the intersection, which reflects the potential of the IST. Some distribution models describing random behavior were thus reviewed. As usual, we chose the most popular one, i.e. the negative exponential distribution, to describe the random arrival of vehicles by low vehicular flows.

After estimating the IST, we converted the estimated IST into fuel consumed based on the test results by FORMOSUN advanced kinetic research center [2], and then further converted the estimated fuel consumed into the corresponding CO<sub>2</sub> emissions using the emissions model suggested by the Intergovernmental Panel on Climate Change (IPCC) [3]. To realize the practical effect of idling stops, we at last conducted a case study on the idling stops of motorcycles at a specified intersection in Taipei city, Taiwan, for the morning peak period on holidays.

In spite of numerous researches about the issues of energy saving and carbon reduction, such as [1], [2], and [3], there has not yet been any study focused on combining the idling stops of motor vehicles at signalized intersections with the emission reduction of greenhouse gas. Therefore, it is quite meaningful and significant for this research in viewpoint of its pilot role in related domains, on the one hand, and the environmental protection, on the other hand.

## 2. MODELING IDLING STOP TIME

Since this research focused on the vehicles arriving at the signalized intersection during red time, we developed the estimation models based on signal red time, and measured the effect of vehicle idling stops in the IST at first. Assuming that the vehicular flow on an approach at a signalized intersection is  $q$  (veh/hr), the signal cycle time is  $t_c$  (sec), and the signal red time is  $t_r$  (sec), the number of vehicles arriving at the intersection during  $t_r$  is then

$$q_r = \frac{q}{3600} \cdot t_r \quad (1)$$

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If the density function of vehicle arrival time during  $t_r$  is  $f(t)$ , the probability of vehicle arrival at time  $t$  is  $f(t)dt$ . The number of vehicles arriving at time  $t$  is thus

$$q_t = q_r f(t) dt = \frac{qt_r}{3600} f(t) dt, \quad 0 \leq t \leq t_r. \quad (2)$$

Let the signal timing begin with red time proceeding from 0 to  $t_r$  sec, then the rest cycle time from  $t_r$  to  $t_c$  sec would be set for green and amber. If all drivers arriving at the intersection at time  $t$  during red time are willing to turn off vehicle engine, the IST could be

$$T_t = (t_r - t)q_t = (t_r - t)q_r f(t) dt = \frac{qt_r}{3600} (t_r - t) f(t) dt, \quad 0 \leq t \leq t_r, \quad (3)$$

where  $(t_r - t)$  is the remaining red time or the IST of individual vehicles. When all vehicle drivers arriving at the intersection during  $t_r$  are willing to trigger an idling stop, we obtain the IST in a signal cycle by integrating (3) with time.

$$T_c = \int_0^{t_r} (t_r - t)q_r f(t) dt = \int_0^{t_r} \frac{qt_r}{3600} (t_r - t) f(t) dt = \frac{qt_r}{3600} \int_0^{t_r} (t_r - t) f(t) dt. \quad (4)$$

Using (4), we further derive the hourly IST as follows:

$$T_h = \frac{3600}{t_c} \cdot T_c = \frac{3600}{t_c} \cdot \frac{qt_r}{3600} \int_0^{t_r} (t_r - t) f(t) dt = q \cdot \frac{t_r}{t_c} \int_0^{t_r} (t_r - t) f(t) dt. \quad (5)$$

When the density function  $f(t)$  is determined, both  $T_c$  and  $T_h$  can be calculated by integration.

Equation (4) and (5) are formulated under the assumption that all drivers turn off vehicle engine on arriving at intersection, and turn it on again until the red time expires. However, in practice, most drivers would rather restart vehicle engine a few seconds earlier due to psychological reason [1]. As a result, the effective IST for each vehicle becomes  $(t_r - t_s - t)$  instead of  $(t_r - t)$ , where  $t_s$  is the advance restart time ahead of the end of red time. Equation (4) and (5) should accordingly be modified as follows:

$$T_c = \int_0^{t_r - t_s} (t_r - t_s - t)q_r f(t) dt = \frac{qt_r}{3600} \int_0^{t_r - t_s} (t_r - t_s - t) f(t) dt, \quad \text{and} \quad (6)$$

$$T_h = \frac{3600}{t_c} \cdot T_c = \frac{3600}{t_c} \cdot \frac{qt_r}{3600} \int_0^{t_r - t_s} (t_r - t_s - t) f(t) dt = q \cdot \frac{t_r}{t_c} \int_0^{t_r - t_s} (t_r - t_s - t) f(t) dt. \quad (7)$$

As illustrated in Figure 1, the horizontal axis is the arrival time at intersection, and the vertical axis represents the corresponding IST. For any vehicle arriving at time  $t$ , there will be an effective IST in an amount of  $(t_r - t_s - t)$  given by it. Integrating the function of effective IST from 0 to  $(t_r - t_s)$ , we obtain the total effective IST in a signal cycle, i.e. the shadow area in Figure 1.

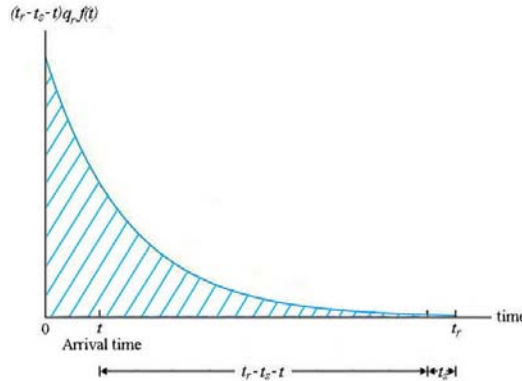


Figure 1. Effective idling stop time

There are several density functions available for the arrival time in traffic stream, of which the Pearson type III distribution can be regarded as one of the most widely used. Its probability density function is given as follows [4, 5]:

$$f(t) = \frac{\lambda}{\Gamma(K)} [\lambda(t - \alpha)]^{K-1} e^{-\lambda(t-\alpha)}, \quad (8)$$

where  $\lambda$ ,  $K$ , and  $\alpha$  are parameters, of which  $K$  and  $\alpha$  are shape and shift parameter, respectively.  $\Gamma(K)$  is gamma function. If  $K$  is integer,  $\Gamma(K)$  is equivalent to  $(K-1)!$ .

The Pearson type III distribution is, in fact, a family of density functions, from which subsets of distribution models can be sorted out. When  $\alpha=0$ , the Pearson type III distribution can be simplified to gamma distribution

$$f(t) = \frac{\lambda}{\Gamma(K)} (\lambda t)^{K-1} e^{-\lambda t}. \quad (9)$$

When  $\alpha=0$  but  $K$  is a positive integer, the Pearson type III distribution becomes Erlang distribution

$$f(t) = \frac{\lambda}{(K-1)!} (\lambda t)^{K-1} e^{-\lambda t}. \quad (10)$$

Let  $\alpha=0$  and  $K=1$ , the Erlang distribution can be further simplified to a single distribution model called the negative exponential distribution as shown in (11), which belongs to one of the most popular distributions for random arrival.

$$f(t) = \lambda e^{-\lambda t}, \quad (11)$$

where  $\lambda$  is the arrival rate.

The Weibul distribution [6], as shown in (12), belongs to another family of density functions probably applied to describing the arrival time.

$$f(t) = \frac{\alpha}{\beta} \left( \frac{t}{\beta} \right)^{\alpha-1} e^{-\left( \frac{t}{\beta} \right)^\alpha}, \quad \text{for } t > 0 \quad (12)$$

with scale parameter  $\beta > 0$  and shape parameter  $\alpha > 0$ .

The scale parameter  $\beta$  reflects the size of the units in which the random variable  $t$  is measured. By changing the value of the shape parameter  $\alpha$ , we can generate a widely varying set of distribution models. For the case  $\alpha=1$ , the Weibul distribution is identical to the negative exponential distribution. Also, the Raleigh distribution is a special case when  $\alpha=2$ .

A variety of composite distributions are another alternative for describing the arrival behavior. Dawson and Chimini [7] developed the hyperlang distribution for the traffic stream on rural roads, which Wu [8] applied to generating the time headways for the simulation of overtaking behavior on two-lane two-way highways in Germany. The hyperlang distribution consists of two components: one is the shifted negative exponential distribution to describe the time headway of free flow, and the other is the Erlang distribution to describe the time headway of disturbed flow. The cumulative function of hyperlang distribution by headway  $h > t$  is

$$F(h > t) = a_1 P_s(h > t) + a_2 P_e(h > t), \quad (13)$$

where  $a_1$  is the proportion of free flow,  $a_2$  is the proportion of disturbed flow,  $P_s$  is the shifted negative exponential distribution, and  $P_e$  is the Erlang distribution.

### 3. MAXIMUM IDLING STOP TIME

If all drivers trigger an idling stop on arriving at the intersection during red time, the IST attains to maximum, as described above. Assume that vehicles randomly arrive at the intersection, and their arrival time conforms to the negative exponential distribution as shown in (11). Let  $\lambda$  be the arrival rate in veh/sec, then

$$\lambda = \frac{q}{3600}. \quad (14)$$

Substitute (11) for  $f(t)$  in (6), we obtain

$$T_c = \int_0^{t_r-t_s} (t_r-t_s-t) q_r \lambda e^{-\lambda t} dt = \lambda q_r \int_0^{t_r-t_s} (t_r-t_s-t) e^{-\lambda t} dt. \quad (15)$$

By integration by parts, we have the condensed form

$$\int uv' dx = uv - \int vu' dx. \quad (16)$$

Let  $u = t_r - t_s - t$ , and  $v' = e^{-\lambda t}$ , so that  $u' = -1$ , and  $v = -\frac{1}{\lambda} e^{-\lambda t}$ . Hence,

$$\int_0^{t_r-t_s} (t_r-t_s-t) e^{-\lambda t} dt = (t_r-t_s-t) \cdot \left. -\frac{1}{\lambda} e^{-\lambda t} \right|_0^{t_r-t_s} - \int_0^{t_r-t_s} \frac{1}{\lambda} e^{-\lambda t} dt = \frac{t_r-t_s}{\lambda} + \frac{1}{\lambda^2} (e^{-\lambda(t_r-t_s)} - 1). \quad (17)$$

Replace  $\int_0^{t_r-t_s} (t_r-t_s-t) e^{-\lambda t} dt$  in (15) with (17), we obtain the maximum IST in a signal cycle

$$T_c = \lambda q_r \left[ \frac{t_r-t_s}{\lambda} + \frac{1}{\lambda^2} (e^{-\lambda(t_r-t_s)} - 1) \right] = q_r (t_r-t_s) + \frac{q_r}{\lambda} [e^{-\lambda(t_r-t_s)} - 1], \quad (18)$$

or

$$T_c = q_r (t_r-t_s) + q_r \cdot \frac{3600}{q} \left[ e^{-\frac{q(t_r-t_s)}{3600}} - 1 \right]. \quad (19)$$

In (19), further substitute  $q_r = \frac{q}{3600} \cdot t_r$ , thus

$$T_c = \frac{q t_r (t_r-t_s)}{3600} + \frac{q t_r}{3600} \cdot \frac{3600}{q} \left[ e^{-\frac{q(t_r-t_s)}{3600}} - 1 \right] = \frac{q t_r (t_r-t_s)}{3600} + t_r \left[ e^{-\frac{q(t_r-t_s)}{3600}} - 1 \right]. \quad (20)$$

From (7) and (18),

$$T_h = \frac{3600}{t_c} \cdot T_c = \frac{3600}{t_c} \left[ q_r (t_r-t_s) + \frac{q_r}{\lambda} (e^{-\lambda(t_r-t_s)} - 1) \right]. \quad (21)$$

Replace  $q_r$  in (21) with (1), we have another form of the maximum hourly IST

$$T_h = \frac{3600}{t_c} \left[ \frac{qt_r(t_r - t_s)}{3600} + \frac{qt_r}{3600\lambda} (e^{-\lambda(t_r - t_s)} - 1) \right] = q \cdot \frac{t_r}{t_c} \left[ t_r - t_s + \frac{1}{\lambda} (e^{-\lambda(t_r - t_s)} - 1) \right], \quad (22)$$

or

$$T_h = q \cdot \frac{t_r}{t_c} \left[ t_r - t_s + \frac{3600}{q} \left( e^{-\frac{q(t_r - t_s)}{3600}} - 1 \right) \right] = \frac{qt_r(t_r - t_s)}{t_c} + \frac{3600t_r}{t_c} \left( e^{-\frac{q(t_r - t_s)}{3600}} - 1 \right). \quad (23)$$

#### 4. PRACTICAL IDLING STOP TIME

In practice, the driver's willingness for idling stops is often restricted by the remaining red time on arriving at the intersection, which depends on the psychological needs of individual drivers. Let the required remaining red time for idling stop be  $t_i$  sec, an idling stop is then triggered when the arrival time  $t$  is earlier as  $(t_r - t_i)$  sec. Referring to (6), we remodeled the IST in a signal cycle conditioned by a required remaining red time as

$$T_c^i = \int_0^{t_r - t_i} (t_r - t_s - t) q_r f(t) dt = q_r \int_0^{t_r - t_i} (t_r - t_s - t) f(t) dt, \quad t_i > t_s. \quad (24)$$

Replace  $f(t)$  again with the negative exponential distribution in (11), we obtain

$$T_c^i = q_r \int_0^{t_r - t_i} (t_r - t_s - t) \lambda e^{-\lambda t} dt = \lambda q_r \int_0^{t_r - t_i} (t_r - t_s - t) e^{-\lambda t} dt. \quad (25)$$

As illustrated in Figure 2, for any vehicle arriving at time  $t$  within  $(t_r - t_i)$ , there will be the same effective IST of  $(t_r - t_s - t)$  as that in Figure 1, but for vehicles arriving later than  $(t_r - t_i)$ , the willingness to trigger an idling stop exists no longer due to insufficient remaining red time. As a result, the practical IST in a signal cycle reduces to the shadow area in Figure 2, which can be obtained by integrating the IST function from 0 to  $(t_r - t_i)$ .

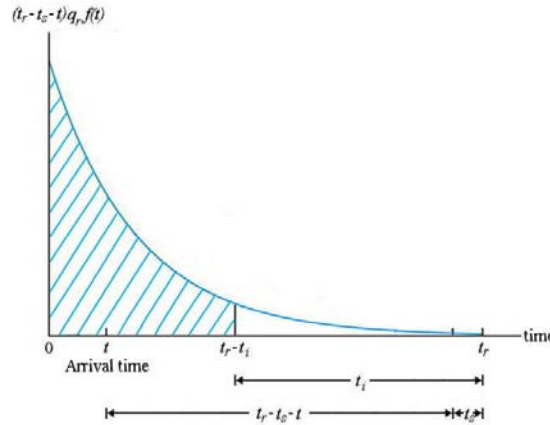


Figure 2. Practical idling stop time

In the same way to integrate by parts for (25), then

$$\int_0^{t_r - t_i} (t_r - t_s - t) e^{-\lambda t} dt = -\frac{1}{\lambda} \left[ (t_i - t_s) e^{-\lambda(t_r - t_i)} - (t_r - t_s) \right] + \frac{1}{\lambda^2} \left[ e^{-\lambda(t_r - t_i)} - 1 \right]. \quad (26)$$

Thus,

$$T_c^i = \lambda q_r \left\{ -\frac{1}{\lambda} \left[ (t_i - t_s) e^{-\lambda(t_r - t_i)} - (t_r - t_s) \right] + \frac{1}{\lambda^2} \left[ e^{-\lambda(t_r - t_i)} - 1 \right] \right\} = q_r \left[ \left( \frac{1}{\lambda} - t_i + t_s \right) e^{-\lambda(t_r - t_i)} + t_r - t_s - \frac{1}{\lambda} \right]. \quad (27)$$

Substituting  $q_r = \frac{q}{3600} \cdot t_r$  in (27), we have another form of the practical IST in a signal cycle

$$T_c^i = \frac{qt_r}{3600} \left[ \left( \frac{1}{\lambda} - t_i + t_s \right) e^{-\lambda(t_r - t_i)} + t_r - t_s - \frac{1}{\lambda} \right], \quad (28)$$

or

$$T_c^i = \frac{qt_r}{3600} \left[ \left( \frac{3600}{q} - t_i + t_s \right) e^{-\frac{q(t_r - t_i)}{3600}} + t_r - t_s - \frac{3600}{q} \right] = \left( t_r - \frac{qt_r(t_i - t_s)}{3600} \right) e^{-\frac{q(t_r - t_i)}{3600}} + \frac{qt_r(t_r - t_s)}{3600} - t_r. \quad (29)$$

Similarly, we derived the practical hourly IST from (7) as

$$T_h^i = \frac{3600}{t_c} \cdot T_c^i = \frac{3600}{t_c} \cdot \frac{qt_r}{3600} \left[ \left( \frac{1}{\lambda} - t_i + t_s \right) e^{-\lambda(t_r - t_i)} + t_r - t_s - \frac{1}{\lambda} \right] = q \cdot \frac{t_r}{t_c} \left[ \left( \frac{1}{\lambda} - t_i + t_s \right) e^{-\lambda(t_r - t_i)} + t_r - t_s - \frac{1}{\lambda} \right], \quad (30)$$

or

$$T_h^i = q \cdot \frac{t_r}{t_c} \left[ \left( \frac{3600}{q} - t_i + t_s \right) e^{-\frac{q(t_r-t_i)}{3600}} + t_r - t_s - \frac{3600}{q} \right]. \quad (31)$$

## 5. CASE STUDY

According to the statistics issued by the Minister of Transportation and Communications [9], the number of motorcycles in Taiwan area has reached 15,174 thousands at the end of 2011, which is double so many as that of the other motor vehicles. It is, therefore, reasonable to focus the case study on the motorcycles. In addition, the countdown devices for signal red time at intersections in Taiwan provide also good condition to implement idling stops. As a specific case, we selected the southbound approach at Keelung-Xinhai intersection in Taipei city, Taiwan, to estimate the effect of idling stops by motorcycles. During the morning peak period on holidays, an average traffic flow of 301 motorcycles per hour was observed on this approach. At this intersection, the signal cycle time is 200 sec, and a 152 sec red time is given to this approach. By a questionnaire survey of the behavior of motorcyclists, Hsiao [10] found that by idling stops, most motorcyclists would rather restart engine earlier than the end of red time to avoid start delay, and the advance restart time was 2.67 sec in average. We, thus, set  $t_s=2.67$  sec by evaluating the IST.

To measure the required remaining red time for idling stops, Hsieh [11] adopted contingent valuation to survey the motorcyclists' willingness for idling stops. Contingent valuation is often referred to as a stated preference model. It is a utility-based economic technique for the valuation of non-market resources. In the study, the survey explored how much remaining red time the motorcyclists are willing to accept for idling stops in order to improve the environment. The results are showed in Table I. About 23% of motorcyclists were, for instance, willing to turn off engine to wait for green if the remaining red time is more than 30 sec, and about 34% required more than 50 sec for idling stops. However, even if the remaining red time is more than 150 sec, there were still 10.77% of motorcyclists unwilling to trigger any idling stop.

TABLE I. REQUIRED REMAINING RED TIME FOR IDLING STOPS

Remaining red time (sec)	Percentage (%)
30	23.05
50	33.99
70	13.99
90	5.14
110	7.13
130	3.81
150	2.15
unwilling	10.77
Total	100

In this case study, hourly flow  $q=301$ , cycle time  $t_c=200$ , red time  $t_r=152$ , and advance restart time  $t_s=2.67$ . Using (31), we could estimate the hourly IST for various required remaining red times in Table I by

$$\begin{aligned} T_h^i &= q \cdot \frac{t_r}{t_c} \left[ \left( \frac{3600}{q} - t_i + t_s \right) e^{-\frac{q(t_r-t_i)}{3600}} + t_r - t_s - \frac{3600}{q} \right] = 301 \cdot \frac{152}{200} \left[ \left( \frac{3600}{301} - t_i + 2.67 \right) e^{-\frac{301(152-t_i)}{3600}} + 152 - 2.67 - \frac{3600}{301} \right] \\ &= 228.76 \left[ (14.63 - t_i) e^{-\frac{301(152-t_i)}{3600}} + 137.37 \right]. \end{aligned} \quad (32)$$

As an instance, by  $t_i=30$  sec, the hourly IST amounts to

$$T_h^i = 228.76 \left[ (14.63 - 30) e^{-\frac{301(152-30)}{3600}} + 137.37 \right] = 31,425 \text{ sec} = 8.729 \text{ hrs.}$$

In the same way, the hourly IST for each required remaining red time was estimated. After weighting by the percentage, we obtained an hourly IST of 7.575 hours, as shown in Table II.

TABLE II. ESTIMATION OF HOURLY IDLING STOP TIME

Remaining red time (sec)	Hourly IST (hrs)	Percentage (%)	Weighted hourly IST (hrs)
30	8.729	23.05	2.012
50	8.729	33.99	2.967
70	8.725	13.99	1.221

90	8.702	5.14	0.447
110	8.548	7.13	0.609
130	7.564	3.81	0.288
150	1.452	2.15	0.031
unwilling	0	10.77	0.000
Total		100	7.575

The estimated IST can be converted into fuel saving directly. The IST indicates the saved time of fuel combustion by engine. If no idling stop is applied, the vehicle engine runs at idle speed, and consumes fuel continuously. On the contrary, by idling stop, the engine is turned off, and stops combusting fuel. Therefore, the fuel saving by idling stops corresponds to the amount of fuel combusted by vehicle engine at idle speed during the IST. According to the study of FORMOSUN advanced kinetic research center [2], the fuel consumed by motorcycles at idle speed is proportional to the time. The test results showed that in average, the motorcycle engine consumed 4.35 ml petrol per minute at idle speed. In other words, the fuel saving in the IST is equivalent to

$$\text{Fuel consumed } (l) = \text{IST (hr)} \times (4.35 \text{ ml/min}) \times (60 \text{ min/hr}) \times (1 \text{ l}/1000 \text{ ml}) = 0.261 \times \text{IST (hr)} \quad (33)$$

By  $\text{IST} = 7.575$  hrs, we can determine the equivalent fuel saving or consumed as

$$\text{Fuel consumed} = 0.261 \times 7.575 = 1.977 \text{ l}$$

The fuel consumed by vehicle engine can be further converted into emissions of greenhouse gas. The IPCC [3] indicated that emissions by road transportation can be estimated from either the fuel consumed (represented by fuel sold) or the distance travelled by the vehicles. In general, the fuel sold is appropriate for  $\text{CO}_2$ , and the distance travelled by vehicles is appropriate for  $\text{CH}_4$  and  $\text{N}_2\text{O}$ . In this study, we focused on the emissions of  $\text{CO}_2$ , which is regarded as one of the major factors resulting in the global warming. Accordingly, we converted the estimated fuel consumed into emissions of  $\text{CO}_2$  using the following equation suggested by the IPCC [3] on the basis of the amount and type of fuel sold, and its carbon content:

$$\text{Emissions of } \text{CO}_2 \text{ (kg)} = \text{fuel sold or consumed } (l) \times \text{CO}_2 \text{ emission factor (kg/l)} \quad (34)$$

The  $\text{CO}_2$  emission factor is equal to the carbon content of the fuel multiplied by 44/12. As a rule, the country-specific carbon content of the fuel sold is used, i.e. the  $\text{CO}_2$  emission factor is based on the actual carbon content of fuel consumed (sold) in the country during the inventory year. It is good practice to use country-specific net-calorific values (NCV) and  $\text{CO}_2$  emission factor data if possible. After a nation-wide investigation of greenhouse gas inventories, the Environmental Protection Administration (EPA) [12] suggested a  $\text{CO}_2$  emission factor of 2.26 kg/l for mobile combustion of vehicle petrol. Multiplying this value by the estimated fuel consumed, we obtain the  $\text{CO}_2$  emissions as

$$\text{Emissions of } \text{CO}_2 = 1.977 \text{ l} \times 2.26 \text{ kg/l} = 4.468 \text{ kg}$$

The 4.468 kg  $\text{CO}_2$  emissions can also be regarded as the amount of  $\text{CO}_2$  reduction due to idling stops. For the 2 hours morning peak period on holiday, the  $\text{CO}_2$  emissions or reduction will be doubled to 8.936 kg. In general, there are two holidays in each week, and 52 weeks in a year. Thus, the number of holidays in a year is 104 days. The total  $\text{CO}_2$  emissions or reduction in a year becomes  $8.936 \text{ kg} \times 104 = 929.344 \text{ kg}$ , almost equal to 1 ton. The related estimation results are shown in Table III.

TABLE III. FUEL SAVING AND  $\text{CO}_2$  REDUCTION DUE TO IDLING STOPS

Effect \ Period	One hour in morning peak period on holiday	Morning peak period on holiday	Morning peak period on holidays in one year
Idling stop time (hrs)	7.575	15.15	787.80
Fuel saving (l)	1.977	3.954	205.608
$\text{CO}_2$ reduction (kg)	4.468	8.936	929.344

The above proposed equations calculate the IST based on the individual idling stops, which incur concern about the increase of fuel consumed and  $\text{CO}_2$  emissions by restarting the engine that might offset the effect of idling stops. To realize the variation of fuel consumed and  $\text{CO}_2$  emissions by time after restarting the engine, the EPA [13] conducted a tedious test for motorcycles. The test found that both fuel consumed and  $\text{CO}_2$  emissions were not significantly increased by restarting the motorcycle engine after a three minute idling stop. In other words, even a large amount of idling stops by motorcycles will not cause extra fuel consumed and  $\text{CO}_2$  emissions. Therefore, the estimated results in Table III are reasonable.

## 6. CONCLUSION AND DISCUSSION

In this research, two kinds of models were developed to estimate the IST at signalized intersections under random arrival of vehicles. The first one was used to estimate the maximum IST under the ideal condition where each driver is willing to trigger an idling stop on arriving at the intersection during the red time. In contrast, the second one appeared more practical to take account of the diversity of individual needs for the required remaining red time in the real life, by which the practical IST could be evaluated. Based on the test results by FORMOSUN advanced kinetic research center [2], we could further convert the estimated IST into fuel consumed, and subsequently the corresponding  $\text{CO}_2$  emissions using the emissions model suggested by the IPCC [3].

A case study, specified for an approach at Keelung-Xinhai intersection in Taipei city, showed that the practical IST of motorcycles would amount to 787.8 hrs for the morning peak period on holidays in a year. A corresponding fuel saving of 205.608 l

could be obtained, which was equivalent to 929.344 kg CO<sub>2</sub> reduction after combusted by the motorcycle engines. The results indicate that idling stops will really help to improve the energy saving and carbon reduction due to the occurrence of a large amount of the IST. If we extend the observation to the four approaches of the intersection, and assume the same traffic flow on these approaches, we can attain about 822 l fuel saving, and 3,717 kg CO<sub>2</sub> reduction. These figures merely represent the effect of idling stops by motorcycles at one intersection during two hour morning peak period on holidays in a year. There are more than 2,000 intersections, mostly installed with countdown devices for red time, in Taipei city, and over 15 million motorcycles in Taiwan [9]. If all motorcyclists are willing to conduct idling stops on red at intersections, the total effects on the environmental protection will be remarkable and significant.

In addition, if measures take effect to raise the driver's willingness for idling stop, not only the proportion of idling stops but also the required remaining red time will be improved. Both will then result in increasing the IST. The Cox proportional hazard model (Cox PHM), based on the survival analysis, is quite appropriate for investigating the factors significantly influencing driver's willingness for idling stops [14]. By changing the value of influence factors, i.e. taking measures to raise driver's willingness for idling stops, we may forecast the increase of the IST, and then the fuel saving as well as the CO<sub>2</sub> reduction in advance. The increment of the IST can be obtained by the median survival times used as the required remaining red times, and depicted in the survival curves. Multiplying it by the increased proportion of willingness estimated by means of analyzing the relative risk, we attain the potential increment of the IST for individual influence factors. Moreover, from the macroscopic point of view, the CO<sub>2</sub> emissions approximated to 3.28 tons per 10 second idling of all motorcycles in Taiwan, estimated by the Institute of Transportation [15]. This amount also reflects a tremendous potential for energy saving and carbon reduction by idling stops. Therefore, it is meaningful and significant to develop estimation models to explore these effects in advance.

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