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รายงานการวิจัย

การศึกษาการเปลี่ยนแปลงคุณลักษณะการไหลจราจร ณ บริเวณทางแยกสัญญาณไฟ จากการติดตั้งอุปกรณ์นับเวลาถอยหลังประกอบสัญญาณไฟ

(Studying the effects of count-down timers on traffic flow characteristics at signalized intersections)

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ได้รับทุนอุดหนุนการวิจัยจากมหาวิทยาลัยเทคโนโลยีสุรนารี ปีงบประมาณ 2549-2550
ผลงานวิจัยเป็นความรับผิดชอบของหัวหน้าโครงการวิจัยแต่เพียงผู้เดียว

กรกฎาคม 2552

กิตติกรรมประกาศ

งานวิจัยนี้ สำเร็จลุล่วงได้ด้วยดี จากความช่วยเหลือจากบุคคลและหน่วยงานต่างๆ ที่เกี่ยวข้องหลายท่าน ผู้เขียนใคร่ขอขอบคุณเจ้าหน้าที่แขวงการทางกรุงเทพ กรมทางหลวง และสถานีตำรวจนครบาลโชคชัย สำนักงานตำรวจแห่งชาติ สำหรับการประสานงานช่วยเหลือการเปิด-ปิดสัญญาไฟนับเวลาถอยหลัง ณ ทางแยกเกษตร-นวมินทร์/ลาดปลาเค้าในช่วงดำเนินการวิจัย เจ้าหน้าที่สำนักการจราจรและขนส่งกรุงเทพมหานคร สำหรับการเอื้อเฟื้อข้อมูลประกอบงานวิจัย และ Associate Professor Dr. Adrian Flood สำหรับความช่วยเหลือในการตรวจทานร่างบทความฉบับภาษาอังกฤษ

ท้ายที่สุด ผู้เขียนใคร่ขอขอบคุณมหาวิทยาลัยเทคโนโลยีสุรนารีเป็นอย่างยิ่ง ที่ได้เอื้อเฟื้ออุดหนุนการวิจัย ปีงบประมาณ 2549-2550 สำหรับโครงการนี้

ถิรยุทธ ลิมานนท์
หัวหน้าโครงการวิจัย
กรกฎาคม 2552

บทคัดย่อ

งานวิจัยนี้ มีวัตถุประสงค์เพื่อศึกษาว่าการติดตั้งอุปกรณ์นับเวลาถอยหลัง ณ ทางแยกสัญญาณไฟ จะมีผลกระทบต่อคุณลักษณะของการไหลจราจรของรถทางตรงที่บริเวณทางแยกอย่างไรบ้าง เนื่องจากอุปกรณ์ฯ ดังกล่าว แสดงระยะเวลา (ในหน่วยวินาที) ก่อนที่จะเปลี่ยนสัญญาณไฟ ทำให้ผู้ขับขี่ในแถวคอยที่ติดสัญญาณไฟแดงอยู่ทราบล่วงหน้าว่าสัญญาณไฟจะเปลี่ยนเป็นสีเขียวเมื่อใด จึงน่าจะส่งผลให้ผู้ขับขี่สามารถเคลื่อนตัวได้ทันทีเมื่อสัญญาณไฟเปลี่ยน ดังนั้น คณะผู้วิจัยจึงได้ตั้งสมมติฐานว่าอุปกรณ์นับเวลาถอยหลัง น่าจะช่วยลดการสูญเสียเวลาในช่วงเริ่มต้นสัญญาณไฟเขียว ลดระยะเวลาระหว่างยวดยาน และเพิ่มอัตราการไหลอิ่มตัวผ่านทางแยกได้ การศึกษานี้ ได้ดำเนินการสังเกตการไหลของยวดยานผ่านทางแยก ณ ทางแยกแห่งหนึ่งในกรุงเทพฯ โดยสำรวจในช่วงที่เปิดสัญญาณนับเวลาถอยหลังเป็นเวลา 24 ชั่วโมง เพื่อนำมาเปรียบเทียบกับสภาพการไหลในขณะที่ปิดอุปกรณ์นับเวลาถอยหลัง ซึ่งดำเนินการสำรวจเป็นเวลา 24 ชั่วโมงเช่นกัน โดยระบบสัญญาณไฟทั้งสองกรณีมีรูปแบบและรอบสัญญาณไฟไม่แตกต่างกัน จากการทดสอบทางสถิติ โดยใช้ t-test เพื่อตรวจสอบความแตกต่างของการไหลจราจรระหว่างสองกรณี พบว่าอุปกรณ์นับเวลาถอยหลัง ส่งผลกระทบต่อการสูญเสียเวลาในช่วงเริ่มต้นสัญญาณไฟเขียวอย่างมีนัยสำคัญ โดยจะช่วยลดการสูญเสียเวลาในช่วงเริ่มต้นสัญญาณได้ 1.00 – 1.92 วินาทีต่อรอบสัญญาณ หรือคิดเป็นการประหยัดเวลา ได้ร้อยละ 17 ถึง 32 อย่างไรก็ตาม ผลกระทบต่อระยะเวลาระหว่างยวดยานในสภาพการไหลอิ่มตัว พบว่าไม่มีนัยสำคัญ ซึ่งบ่งบอกว่าอุปกรณ์นับเวลาถอยหลังแทบจะไม่มีมีผลกระทบต่ออัตราการไหลต่อทางแยกสัญญาณไฟ หรืออาจจะมีแต่มีปริมาณน้อยมาก โดยเฉพาะอย่างยิ่งในช่วงเวลานอกเร่งด่วนและช่วงเวลากลางคืน สำหรับการประหยัดการสูญเสียเวลาในช่วงเริ่มต้นไฟเขียว ประเมินว่าจะช่วยเพิ่มความจุจราจรบริเวณทางแยกได้มากขึ้น ประมาณ 8 – 24 คัน/ช่องทาง ณ ทางแยกสัญญาณไฟที่ศึกษา

Abstract

This study investigates how countdown timers installed at a signalized intersection affect the queue discharge characteristics of through movement during the green phase. Since the countdown timers display the time remaining (in seconds) until the onset of the green phase, drivers waiting in the queue at the intersection are aware of the upcoming phase change, and are likely to respond quicker. Thus, the countdown timers could reduce the start-up lost time, decrease the saturation headway, and increase the saturation flow rate. This study observed vehicle flow at an intersection in Bangkok for 24 h when the countdown timers were operating, and for another 24 h when the countdown timers were switched off. The signal plans and timings remained unchanged in both cases. Standard statistical t-tests were used to compare the difference in traffic characteristics between the ''with timer'' and ''without timer'' cases. It was found that the countdown timers had a significant impact on the start-up lost time, reducing it by 1.00–1.92 s per cycle, or a 17–32% time saving. However, the effects on saturation headway were found to be trivial, which implies that the countdown timers do not have much impact on the saturation flow rate of signalized intersections, especially during the off-peak day period and the late night period. The savings in the start-up lost time from the countdown timers was estimated to be equivalent to an 8–24 vehicles/h increase for each through movement lane at the intersection being studied.

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บทนำ

งานวิจัยนี้ ได้ดำเนินการแล้วเสร็จ และเนื้อหาทั้งหมดได้จัดทำเป็นบทความภาษาอังกฤษชื่อว่า Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection โดยคณะผู้วิจัยประกอบด้วย ถิรยุทธ ลิมานนท์ สืบพงศ์ ชูเกิด และณัชฌา รวบทองหลาง บทความดังกล่าวได้รับการอนุมัติตีพิมพ์ในวารสารนานาชาติชื่อ Transportation Research Part C (Impact Factor เท่ากับ 1.08) เมื่อเดือนมิถุนายน 2552 และกำลังรอตีพิมพ์เป็นเอกสารต่อไป โดยบทความฉบับนี้ มีเนื้อหาครอบคลุมวัตถุประสงค์ของโครงการ

ดังนั้น รายงานฉบับนี้ จะเป็นลักษณะรายงานอ้างอิงบทความเป็นหลัก โดยคณะผู้วิจัยได้แนบบทความไว้ในภาคผนวกสำหรับอ้างอิงด้วย

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Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection

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Effects of countdown timers on queue discharge characteristics of through movement at a signalized intersection

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ABSTRACT

This study investigates how countdown timers installed at a signalized intersection affect the queue discharge characteristics of through movement during the green phase. Since the countdown timers display the time remaining (in seconds) until the onset of the green phase, drivers waiting in the queue at the intersection are aware of the upcoming phase change, and are likely to respond quicker. Thus, the countdown timers could reduce the start-up lost time, decrease the saturation headway, and increase the saturation flow rate. This study observed vehicle flow at an intersection in Bangkok for 24 h when the countdown timers were operating, and for another 24 h when the countdown timers were switched off. The signal plans and timings remained unchanged in both cases. Standard statistical *t*-tests were used to compare the difference in traffic characteristics between the "with timer" and "without timer" cases. It was found that the countdown timers had a significant impact on the start-up lost time, reducing it by 1.00–1.92 s per cycle, or a 17–32% time saving. However, the effects on saturation headway were found to be trivial, which implies that the countdown timers do not have much impact on the saturation flow rate of signalized intersections, especially during the off-peak day period and the late night period. The savings in the start-up lost time from the countdown timers was estimated to be equivalent to an 8–24 vehicles/h increase for each through movement lane at the intersection being studied.

1. Introduction

The signal countdown timer is an Advanced Traffic Information System that is increasingly popular in traffic congested Asian cities. The timer is a digital clock installed next to the signal head, continuously displaying the number of seconds remaining for each phase of the cycle, including the changes from green to amber, amber to red, and red to green. This timer offers drivers an exact indication of the onset of the next phase so that the drivers are able to make a better decision on how they should respond to the upcoming change, or how they should utilize the time waiting for the onset of the green phase. The countdown timer is often claimed to offer many benefits, including improvement of vehicle flow at the intersection, reduced occurrence of accidents, and the reduction of stress in drivers waiting in the queue (Kasetsart University, 2004).

One potential benefit of the countdown timer is an improvement in the queue discharge since the timer alerts drivers in the queue of the exact phase onset before the queue receives a green phase. However, there have been only a small number of studies investigating this behavior, and the results are still mixed. This study aims to analyze the impact of the signal

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countdown on the queue discharge characteristics during the green interval. In particular, this study attempts to investigate whether or not the installation of countdown timers reduces the start-up lost time, decreases the saturation headway, or increases the saturation flow rate on the through movement at the signalized intersection studied.

2. Literature review

The majority of the previous studies that are related to the traffic light change anticipation system (TLCAS) focused primarily on road safety and accident prevention aspects during the amber phase and the beginning of the red phase. The anticipation system for the onset of the amber/red phase has been implemented for several decades in a variety of ways, including a flashing signal phase and the green signal countdown device. The flashing signal system alerts drivers by using the flashing green phase, or the flashing amber phase simultaneously with the solid green phase, a few seconds before the onset of the solid amber phase. This offers drivers longer decision periods to make an appropriate decision for the upcoming phase change. It is conceivable that such devices would improve safety and reduce the frequency of accident occurrences at signalized intersections. However, a laboratory simulation study by Mahalel et al. (1985) found that the flashing green phase led to a higher number of improper stopping decisions, and thus increased the frequency of rear-end collisions at the intersection. Simulation studies on the flashing amber phase during the last seconds of the solid green by Mussa et al. (1996) and Newton et al. (1997) showed similar results. The anticipation system tends to widen the time period during which drivers are indecisive, and could thus result in an increase in rear-end collisions. Nevertheless, their investigations found that the flashing amber phase potentially reduces severe decelerations and decreases the occurrences of red-light violations.

TLCAS was finally studied in the field in the investigation of Koll et al. (2004). The researchers conducted a survey at 10 intersections in Switzerland, Austria and Germany that used a flashing green phase. The results confirmed the findings of earlier simulation studies; the flashing phase results in a longer time period of indecision, thus tending to increase the frequency of rear-end collisions. However, the system increases the number of early stops, which in turn, reduces the occurrence of right-angle accidents.

A more recent version of TLCAS is the green phase countdown device. It is a countdown timer that displays nil for most of the cycle time, but shows the time remaining before the onset of the solid amber phase as a single digit number in seconds (from 9 to 0). This device not only warns drivers of the upcoming phase change, similar to the flashing phases, but also notifies drivers of the exact instance when the onset will occur. Lum and Halim (2006) conducted a before-and-after study of this type of device at an intersection in Singapore. The study found a 65% decrease in red-light violations 1.5 months after the device was installed, but after 7.5 months the number of red-light violations had rebounded to the average level before the installation. The device also increases the number of vehicular stops within 2 s into the red signal, and this effect seems to be sustained over a long period.

Another ATIS device that is capable of influencing drivers in a similar fashion is the pedestrian countdown signal. Although the real purpose of the pedestrian countdown signals is to offer information for pedestrians crossing the intersection, local commuters usually utilize the information from the pedestrian crossing phases to assist their decision making. Drivers can estimate the time remaining until their signal changes by considering the time remaining in the corresponding pedestrian signal countdown. Albeit most of the pedestrian countdown research primarily investigated its impacts on pedestrian behavior (Kim et al., 2002; Keegan and O'Mahony, 2003; PHA Transportation Consultants, 2005), there is at least one study exploring the impact of the pedestrian countdown signal on driver behavior. Huey and Ragland (2006) compared driver behavior at two intersections in Berkeley, CA; one with the installation of pedestrian countdown signals, and one without. It was found that the countdown signals resulted in fewer vehicles entering the intersection at the end of the amber phase. This could be due to the extra information from the pedestrian countdown signal assisting drivers to make better decisions on whether to speed up to cross the intersection before the amber phase ends, or to slow down and stop at the intersection.

In summary, there are a few TLCAS applications that have been applied for improved traffic control, for example the flashing green or flashing amber phases, the green signal countdown device, and also the pedestrian signal countdown. Most of the previous studies focused on the accident prevention and road safety aspects of these devices, and primarily investigated the TLCAS's impacts on driver behavior during the onset of the amber phase and the beginning of the red phase. The results of previous studies on these devices supports the idea that the anticipation system reduces the frequency of red-light violations and thus right-angle collisions, but could increase "indecision zone" and thus increase the frequency of rear-end accidents.

Continuous countdown timers have been employed for less than a decade but have already become widespread in traffic-congested cities in Thailand, Malaysia and China. Thus far, to the author's knowledge, there have been only two studies (by the same research team) that have attempted to investigate the impact of the signal timer on the discharge of queued vehicles during the beginning of the green phase. Kidwai et al. (2005) analyzed vehicular discharge at a non-CBD intersection in Malaysia, before and after the installation of the countdown timer. The study found the unexpected result that the average throughput (in units of pcu/h) reduced after the installation, which contradicted the presumption of the researchers. However, the statistical tests performed show no significant difference between the "without timer" and the "with timer" conditions at a 95% confidence interval. The researchers concluded that the countdown timers cause "very little effect" on the intersection capacity, without further explanation.

Another study, Ibrahim et al. (2008), attempted to analyze the impact of the countdown timer on traffic flow by comparing the queue discharge patterns between three intersections with signal timers and three intersections without signal timers in Malaysia. Their graphical analysis showed that the mean headways for the first six vehicles in the queue at the intersections with countdown timers were less than the mean headways of the corresponding six positions at the intersections without countdown timers. The study concluded that the countdown timer had a significant effect on the discharge headway of the first six vehicles in the queue, though there was no corresponding statistical analysis used to prove the findings. In conclusion, studies of the impact of countdown timers on queue discharge patterns are scarce, focus on one geographic area, yet produced mixed results. This highlights a need for additional studies to investigate the signal countdown impact in detail, and perhaps the need to perform similar studies in other geographical areas.

3. Methodology

The saturation flow rate and the start-up lost time in this study were determined based on the conventional approach, presented in the Highway Capacity Manual (Transportation Research Board, 2000). Fig. 1 displays a conceptual headway pattern of the vehicles in the standing queue when the approach receives a green phase. The first few vehicles in the queue generally take a few extra moments to think and react to the signal change by proceeding through the intersection. The headway of successive vehicles gradually decreases until it finally reaches a relatively stabilized interval through the rest of the queue. This stable interval is referred to as the saturation headway.

The determination of the *i*th vehicle in the queue that begins to sustain the saturation headway is a challenging task. The Highway Capacity Manual 2000 suggests the fifth vehicle to be the start of the saturation headway, however this variable strongly depends on many locality factors, such as driving culture, level of congestion, signal cycle length, average size of vehicles, driver's age, and driver perception. This research utilized a series of the standard *t*-statistics tests, similar to previous studies of Joseph and Chang (2005) and Raksutorn (2004), to identify the order of the vehicle in the queue that first sustains the saturation headway. The detailed procedure is as follows:

Let $\overline{H}_i$ denotes the mean headway of the *i*th vehicle in the queue from the measurements of a few signal cycles, which is estimated as:

$$\overline{H}_i = \frac{\sum_{x=1}^{c} H_{ix}}{C} \tag{1}$$

where H_{ix}, the headway of the *i*th vehicle in the queue measured from the cycle *x*th; *C*, the number of the signal cycles in considerations.

Then, assume $\overline{H}_i^q$ is the average headway accumulated from the *i*th vehicle to the last vehicle in the standing queue.

$$\overline{H}_i^q = \frac{\sum_{x=1}^{c}\sum_{i}^{q} H_{ix}}{\sum_{x=1}^{c}\sum_{i}^{q} i} \tag{2}$$

where H_{ix}, the headway of the *i*th vehicle in the queue measured from the cycle *x*th; *q*, the last vehicle in the standing queue.

For example, $\overline{H}_1^q$ is the average headway of all vehicles in the standing queue (accumulated from the first vehicle to the last vehicle in the queue, estimated from a few cycles), or $\overline{H}_3^q$ refers to the average headway accumulated from the third vehicle to the last vehicle in the standing queue.

The identification of the *i*th vehicle in the queue that begins to experience the stabilized headway follows the steps below.

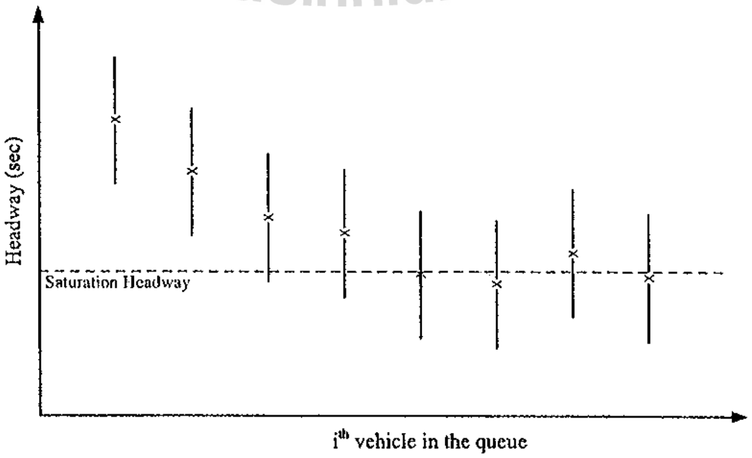


Fig. 1. Conceptual headway pattern of vehicles in a standing queue.

Step 1: Determine the average headway of the first vehicle in the queue ($\overline{H}_1$).
Step 2: Determine the average headway accumulated from the second vehicle to the last vehicle in the queue, $\overline{H}^a_2$.
Step 3: Use a t-test to check whether $\overline{H}_1$ is statistically different from $\overline{H}^a_2$. If no, stop the procedure. If yes, proceed to Step 4.
Step 4: Determine the average headway of the second vehicle in the queue ($\overline{H}_2$) and the average headway accumulated from the third vehicle to the last vehicle in the queue ($\overline{H}^a_3$). Then, again use a t-test to investigate whether $\overline{H}_2$ is statistically different from $\overline{H}^a_3$. If yes, proceed to test whether $\overline{H}_n$ is statistically different from $\overline{H}^a_{n+1}$, where $n = 3, 4, 5, \ldots$, respectively.
Step 5: Stop the procedure when $\overline{H}_n$ is not statistically different from $\overline{H}^a_{n+1}$. Then, the nth vehicle is the first vehicle in the queue that sustains the saturation headway.

When the nth vehicle has been identified, we can estimate the saturation headway (H_{sat}) as:

$$H_{sat} = \overline{H}^a_n \tag{3}$$

The saturation flow rate (V_{sat}) of the approach is simply the reciprocal of the saturation headway.

$$V_{sat} = \frac{1}{H_{sat}} \times 3600 \tag{4}$$

The start-up lost time is determined as the sum of the additional time over the saturation headway experienced by the vehicles in the queue before the first vehicle to reach the saturation headway. It can be estimated using Eq. (5).

$$\mathrm{SULT} = \sum_{1}^{n-1} H_i - [(n-1) \times H_{sat}] \tag{5}$$

where SULT, start-up lost time (s); H_i, the average headway of the ith vehicle in the queue (s); H_{sat}, the saturation headway (s); n, the order of the vehicle in the queue that begins to sustain the saturation headway.

3.1. *Project site selection*

After an extensive survey throughout the city of Bangkok, the Kaset-Navamin Road/Lad Pra Kao Road intersection was selected. This is an intersection in a non-CBD location in Bangkok and fulfills all of the pre-identified conditions in the study. The study particularly focuses on the through movement on the eastbound approach along Kaset Navamin Road. This approach comprises of two left-turn lanes (free-flow), three through lanes and one right-turn lane. The signal phasing plan utilizes a lagged right-turn phase for the east–west approach, and a split phase for the north–south approach. The intersection is equipped with countdown timers for all of the four approaches. In general, the signal countdown timers are on operation throughout the day except for the morning and evening peak hours when traffic police take control and manually adjust the traffic signals. During these periods, the signal plans and timings are run unsystematically according to judgment of the traffic police, and thus the countdown timers are usually turned off (displaying nil). Thus, the vehicle flows during the peak periods were excluded from the investigation.

A video camera was used to record the vehicular flow on the eastbound approach for 24 h while the countdown timer was on operation. Exactly 1 week after the initial data was recorded, the research team requested the department of highways to turn off the countdown timers without any modifications of the traffic signal and timings, and the flow of traffic on the same approach was recorded for an identical 24 h. The later case was used to represent the without countdown timer conditions, as drivers have no knowledge of the exact onset of green phase, similar to the situation when the timer was not installed. It was considered important to have the control condition at the same intersection, to avoid any uncontrollable factors that could occur when two different intersections are analyzed.

This study particularly focused on the vehicular flow on the second and third through lanes of the eastbound approach. We utilized a standard statistical tool, the t-test, to determine whether the start-up lost time and the saturation headway of the "with timer" condition are statistically different from those of the "without timer" case. The intersection signal operates with a cycle length of 230 s during the off-peak day time and the night time, while it runs with a 151-s cycle length during the late night to the early morning. Table 1 summarizes the signal operations and the traffic parameters observed on the eastbound through lanes for both the "with timer" and the "without timer" conditions.

As shown, the data collected was grouped into three study periods: off-peak day time, night time, and late-night time, since each period has distinct characteristics that will affect the queue discharge patterns. The off-peak day time is the period from 10:00 to 15:00, and there is consistently high traffic demand throughout this period. In addition, it is during working hours, and thus most drivers seem to rush, either to reach a place of employment or to attend a business meeting. During the night time, which is the period from 20:00 to 22:00, drivers generally feel less constrained by time; nevertheless, traffic demand on Bangkok streets still remains high, comparable to the off-peak day time (see the observed queue lengths and the observed throughputs in Table 1). Finally, during the late-night time (22:00–02:00), traffic demand is generally dissipated, and drivers do not seem to hurry to reach their destinations within a given time. The broad characteristics of different study periods are summarized in Table 2 below.

Table 1
Summary of the signal operations and traffic parameters of the eastbound through lanes.

Study periods	Duration*	No. of cycles analyzed	Cycle length/green time (min)	Range of observed queue length (vehicle/cycle)	Range of observed throughput (vehicle/cycle)
With countdown timer – surveyed on 25 April 2007					
Day	10:00–15:00	78	230/102	14–33	31–57
Night	20:00–22:00	31	230/102	16–32	32–60
Late night	22:00–02:00	185	151/65	1–15	2–28
Without countdown timer – surveyed on 2 May 2007 (timer off)					
Day	10:00–15:00	78	230/102	14–37	31–56
Night	20:00–22:00	31	230/102	16–37	26–55
Late night	22:00–02:00	189	151/65	2–9	2–28

* Morning peak and evening peak periods were excluded from the analysis, because traffic police take control of the intersection and use random cycle phasing plans and timings.

Table 2
Characteristics of the three study periods.

Characteristics	Study periods		
	Day	Night	Late night
Traffic intensity	High	High	Low
Driving mentality	Rushed	Relaxed	Relaxed

4. Results

Based on the queue discharge pattern suggested in the Highway Capacity Manual 2000, the authors used the statistical *t*-test to determine the order of the vehicle in the standing queue that first sustains the saturation headway using the five-step process described earlier. The results are summarized in Table 3. During the off-peak day time, up to 8 and 10 vehicles pass through the intersection before the saturation headway state emerges for the "with timer" and the "without timer" conditions respectively. However, during the night time and late-night time periods, the saturation headway condition begins from the 5th or the 6th vehicle through the intersection.

4.1. Effects of the time of day on the saturation headway

As mentioned earlier, each study period has its own characteristics that could affect the queue discharge characteristics. It is informative to study the relationship between the time of day and the saturation headway. Table 4 summarizes descriptive statistics of saturation headways during the three study periods under both the "with timer" and the "without timer" conditions. During the periods where the timer was in use, the mean saturation headway gradually increases from 1.88 s/vehicle during the off-peak day time, to 1.94 s during the night period, and finally to 2.05 s during the late night period. Similarly, for the without timer condition, the mean saturation headway progressively increases from 1.85 s/vehicle during the off-peak day time to 2.05 and 2.09 s for the night time and the late-night time periods, respectively. These results are logical given that the day time generally has a high level of traffic demand, and drivers are generally compelled to reach the destination within a pre-defined timeframe. Thus, they tend to drive leaving only a small gap to the vehicle in front of them. This results in the smallest saturation headway occurring during the off-peak day time. Alternatively, traffic demand is much less during the late night period, and drivers are not compelled to rush to their destination, thus drivers tend to leave a larger gap to the vehicle in front of them. Thus, the late night period has the largest saturation headway.

The *t*-tests confirm that the saturation headway depends on the time of day. As shown in Table 5, the off-peak daytime mean saturation headway was statistically different from its nighttime counterpart at the 95% confidence interval for both the "with timer" and "without timer" conditions. However the tests of the mean difference between the night and the late night periods provided mixed results. In the period where the timers were used the *t*-test confirms a significant difference in the mean saturation headway between the night period and the late night period, but no significant difference was found for

Table 3
Summary of the order of the vehicle first sustaining the saturation headway state.

Study periods	ith vehicle to first sustain the saturation headway state	
	With timer	Without timer
Day (off-peak)	8	10
Night	6	5
Late night	5	6

Table 4
Comparisons of saturation headway and saturation flow rate.

Study period	First vehicle to sustain saturation headway	No. of data in the saturation headway state	Saturation headway (s/vehicle)		Equivalent saturation flow (vehicles/h)
			Mean	Std dev	
With countdown timer – surveyed on 25 April 2007					
Day	8	2469	1.88	0.82	1918
Night	6	1024	1.94	0.76	1855
Late-night	5	454	2.05	0.79	1757
Without countdown timer – surveyed on 26 May 2007 (timer off)					
Day	10	2305	1.85	0.80	1946
Night	5	899	2.05	0.94	1756
Late-night	6	395	2.09	0.86	1724

Table 5
Results of t-tests checking the significance of the difference in the mean saturation headway for different study periods.

Study period	Day time (off-peak)		Night time		Different variance?[a]	t-Stat.	p-Value
	N	μ (σ^2)	N	μ (σ^2)			
With timer	2469	1.88 (0.82)	1024	1.94 (0.76)	No	−2.144	0.032
W/O timer	2305	1.85 (0.80)	899	2.05 (0.94)	Yes	−5.643	0.000
Time of day	Night time		Late-night time				
With timer	1024	1.94 (0.76)	454	2.05 (0.79)	No	−2.495	0.013
W/O timer	899	2.05 (0.94)	395	2.09 (0.86)	No	−0.679	0.497

[a] Results from Levene's test for equality of variances at 95% confidence interval.

the "without timer" condition. One plausible explanation follows. The saturation flow rate during the night period (20:00–22:00) and the late night period (22:00–2:00) at a typical signalized intersection without countdown timers are comparable, as drivers are not pressured by time constraints after working hours. Although traffic demand is much dissipated during the late night period, this does not seem to have a significant effect on the saturation headway when the intersection is not equipped with the countdown timers. The installation of the countdown timers, however, appears to cause a statistically significant reduction in the saturation headway during the night (see the additional explanation below), but provides little impact during the late night.

4.2. Effects of the countdown timer on the saturation headway

Table 6 demonstrates that there is no statistically significant difference between the mean saturation headways for periods where countdown timers were in use and periods without countdown timers for most of the study periods. The results of the t-tests show that the only period that did show a significant difference in the mean saturation headway (based on a 95% confidence interval) was during the night time period. These findings imply that the installation of the countdown timers generally has little impact on the saturation headway (and thus the saturation flow) of the through movement. Perhaps, during the off-peak day period, queuing drivers are generally forced by time constraints, so they intend to arrive at their destination within the quickest time possible. Thus, they are likely to leave a small but safe gap to the vehicle in front while proceeding through the intersection. This leads to the minimal saturation headway possible, irrespective of whether countdown timers are in use or not. The installation of the countdown timer appears to have little or no impact on the saturation headway as the daytime saturation flow rate already seems to achieve its optimized state. After working hours, drivers seem to feel less constrained by time, thus they drive less aggressively and tend to leave a larger gap to the vehicle in front. Some drivers in the standing queue pay less attention to the traffic signal, so they do not react quickly when the queue begins to move. This leads to a larger saturation headway during the night time. With countdown timers, however, queuing drivers know the exact moment of the upcoming green phase onset, so they can react promptly. Thus the platoons of vehicles generally proceed through the intersection with less delay, which result in a smaller saturation headway during the night time

Table 6
Result of t-tests checking the significance of the difference in mean saturation headway for with and without timer conditions.

Study period	With timer		Without timer		Different variance?[a]	t-Stat.	p-Value
	N	μ (σ^2)	N	μ (σ^2)			
Day	2469	1.88 (0.82)	2305	1.85 (0.80)	No	1.125	0.261
Night	1024	1.94 (0.76)	899	2.05 (0.94)	Yes	−2.791	0.005
Late-night	454	2.05 (0.79)	395	2.09 (0.86)	No	−0.682	0.495

[a] Results from Levene's test for equality of variances at 95% confidence interval.

in intersections with countdown timers activated. Nevertheless, the same effect does not occur during the late-night time period, possibly due to the low level of traffic demand during this period.

It should be noted that the mean saturation flow rate during the night time period decreases by 0.11 s/vehicle when the countdown timers are used. This makes the saturation flow rate increase from 1756 vehicles/h without timers to 1855 vehicles/h with timers (see Table 4 above), an increase of approximately 100 vehicles/h. The saturation flow rate was in the range of 1919–1946 vehicles/h during the off-peak day time, and the range of 1724–1757 vehicles/h during the night time period.

4.3. *Effects of the countdown timer on the start-up lost time*

The analysis of start-up lost time (SULT) requires some adjustments to the previous computations in order to make a comparison between the "with timer" and the "without timer" conditions with the same basis. First, the order of the vehicle in the standing queue that first sustains the saturation headway has to be equal between the two conditions, otherwise one sums more headway data than the other. Second, the saturation headways of the two conditions must be assumed to be of the same magnitude, or else it is difficult to justify whether the estimated SULTs of one condition is higher than the other. The adjusted values utilized in the analysis as well as the estimated SULTs are shown in Table 7.

As shown in Table 7, the mean SULTs with countdown timers are less than those without timers for all three study periods. The SULT reduces from 8.32 to 6.53 s (or a 22% reduction) during the off-peak day time period, from 5.92 to 4.92 s (or a 17% decrease) during the night time period, and from 5.95 to 4.03 s (or a 32% decrease) during the late-night time period. This is logical given that queuing drivers anticipate the upcoming phase change from the countdown timers, so they are ready to proceed through the intersection without much delay compared to when countdown timers are not used. This results in a decrease in the SULT when countdown timers are used. A series of *t*-tests proved that the mean SULTs between the with and without timer conditions were statistically different at a 95% confidence interval for all three study periods (see Table 8).

In summary, one can reasonably assume that the installation of countdown timers at a signalized intersection will reduce the SULTs occurring during the beginning of the green phase for all three periods analyzed. However, each period displays a reduction of different magnitude. The saving in the SULT was approximately 1.79 seconds per cycle (or a 22% reduction) during the off-peak day time. The savings in SULT were 1.00 seconds per cycle (or 17%) and 1.92 seconds per cycle (or 32%) for the night time period and the late-night time period, respectively.

Note that the estimated SULTs calculated here should not be directly compared across different time periods in the day, because the data was calculated based on different bases, e.g., they have a different order of the vehicle in the standing queue that first sustains the saturation headway state, or a different saturation headway.

To further explore the impacts of countdown timers on individual vehicles in the standing queue, the paired individual headways between the conditions with and without timers were analyzed, as summarized in Table 9 and Fig. 2. The impact of the countdown timers in reducing individual headways are largest on the first vehicle; 1.24 s during the off-peak day time, 0.85 s during the night time, and 1.55 s during the late-night time. The impact, however, quickly dissipated on the second vehicle, and was further reduced for subsequent vehicles (as shown in both the table and the figure). Statistical tests demonstrate that the difference in the individual headway are significant at 95% confidence interval for the first vehicle in the standing queue only, and are insignificant for the rest of the queue. This indicates that the countdown timers have significant effects on the headway of the first vehicles only.

5. Discussion and conclusions

The objective of this study was to investigate the effect of countdown timers on the queue discharge characteristics of the through movement during the green period of a signalized intersection. A major intersection with countdown timers in-

Table 7
Comparisons of start-up lost time.

Study period	First vehicle to sustain saturation headway (ith)	Weighted average saturation headway (s/vehicle)	No. of cycles analyzed	Start-up lost time (s)	
				Mean	Std dev
With countdown timer – surveyed on 25 April 2007					
Day	8	1.87	139	6.53	1.76
Night	6	1.99	51	4.92	1.80
Late night	5	2.11	121	4.03	1.72
Without countdown timer – surveyed on 26 May 2007 (timer off)					
Day	8[a]	1.87	122	8.32	2.06
Night	6[a]	1.99	35	5.92	1.25
Late night	5[a]	2.11	137	5.95	1.54

[a] Adjusted vehicle to sustain saturation headway state, to make the comparison on the same basis.

Table 8
Result of t-tests for checking the significance of the difference in mean start-up lost time between with and without timer conditions.

Time of day	With timer		Without timer		Variance different?[a]	t-Stat.	p-Value
	N	$\mu\ (\sigma^2)$	N	$\mu\ (\sigma^2)$			
Day	139	6.53 (1.76)	122	8.32 (2.06)	No	−7.551	<0.001
Night	51	4.92 (1.80)	35	5.92 (1.25)	No	−2.853	0.005
Late night	121	4.03 (1.72)	137	5.95 (1.54)	No	−9.487	<0.001

[a] Results from Levene's test for equality of variances at 95% confidence interval.

Table 9
The difference in mean individual headways of the first few vehicles in the standing queue for the with and without timer conditions.

		Mean headway (s)							
	ith vehicle	1	2	3	4	5	6	7	8
Day	With timer	5.66	2.67	2.50	2.33	2.26	2.05	2.10	1.98
	Without timer	6.90	2.87	2.44	2.46	2.24	2.25	2.19	2.01
	Difference	−1.24	−0.20	0.06	−0.13	0.02	−0.20	−0.09	−0.03
	Sig. at 95% CI?	Yes	No	No	No	No	No	No	No
Night	With timer	5.41	2.54	2.52	2.18	2.23	2.02		
	Without timer	6.26	2.79	2.37	2.49	2.01	2.11		
	Difference	−0.85	−0.25	0.15	−0.31	0.22	−0.09		
	Sig. at 95% CI?	Yes	No	No	No	No	No		
Late night	With timer	5.05	2.77	2.44	2.27	2.13			
	Without timer	6.60	2.73	2.46	2.59	2.38			
	Difference	−1.55	0.04	−0.02	−0.32	−0.25			
	Sig. at 95% CI?	Yes	No	No	No	No			

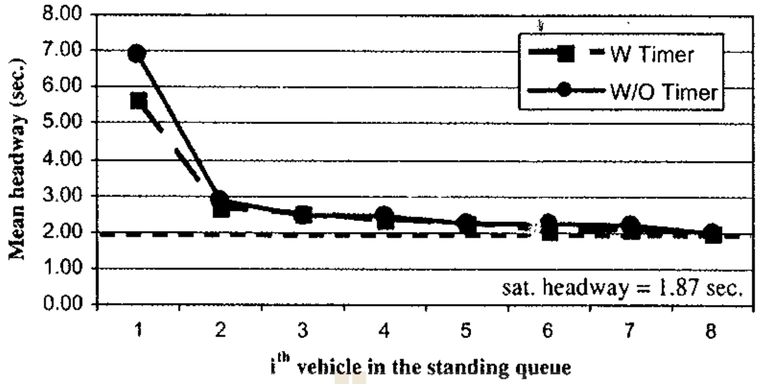
Note: Sig. – significant, CI – confidence interval.

stalled, located in Bangkok was carefully selected to be the study site. Twenty-four-hour vehicular flow on the eastbound through lanes was recorded twice, a week apart: the first analysis was performed when the countdown timer was in operation as usual, and the second analysis was performed when the countdown timer was switched off, with the traffic signals remaining in operation with the same signal plans and timings. The headway data was extracted and analyzed, and compared to investigate the difference in queue discharge characteristics between the two conditions analyzed.

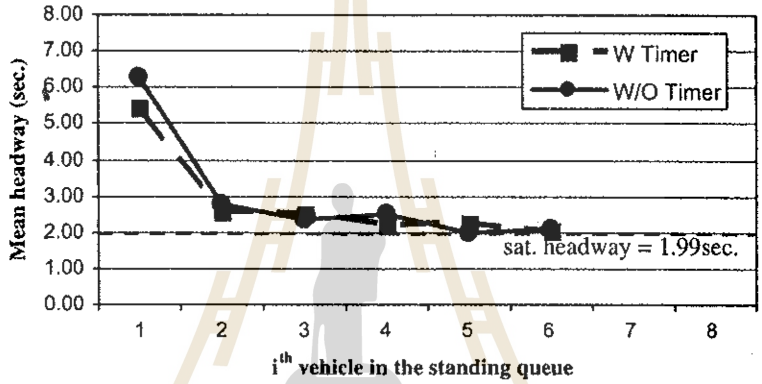
The comparison of queue discharge characteristics with and without countdown timers yields two interesting implications. Firstly, the countdown timers helped reduce the SULT on the through movement: the mean SULTs for the periods with countdown timers were consistently less than that those for the periods without timers for all three study periods. It reduced SUTL by 1.79 seconds per cycle (or a 22% reduction) during the off-peak day time, 1.00 seconds per cycle (or a 17% decrease) during the night time period, and 1.92 seconds per cycle (or a 32% decrease) during the late-night time period. The results from t-tests demonstrated that the mean SULTs between the "with timers" and the "without timers" conditions are all statistically different at the 95% confidence interval. The countdown timer notifies drivers in the standing queue the exact time of the green onset, so that drivers anticipate and react to the phase change without much delay, particularly the first vehicle in the queue.

Secondly, the countdown timers do not have much effect on the saturation headway of the through movement. The mean saturation headways for periods with the countdown timer were comparable to those for periods without timers during both the off-peak day time and the late-night time periods. Given the high traffic demand and increased time constraints, the saturation headway during the off-peak day time already reaches its optimized (minimal) state without countdown timers. Thus, the installation of the timers has little effect on the saturation headway, and hence the saturation flow rate, during the off-peak day time period. However, the countdown timers seem to alter the saturation headway after working hours, when traffic demand is still high, from 20:00 to 22:00 in this study. Perhaps, the countdown timers concentrate driver attention on the upcoming green onset, so cars proceed through the intersection with shorter headways than if the timer was not operating. Hence, the mean saturation headway was reduced by 0.09 s/vehicle. This is equivalent to a significant improvement to the saturation flow rate of 100 vehicle/h, increasing the saturation headway from 1756 vehicles/h to 1855 vehicles/h.

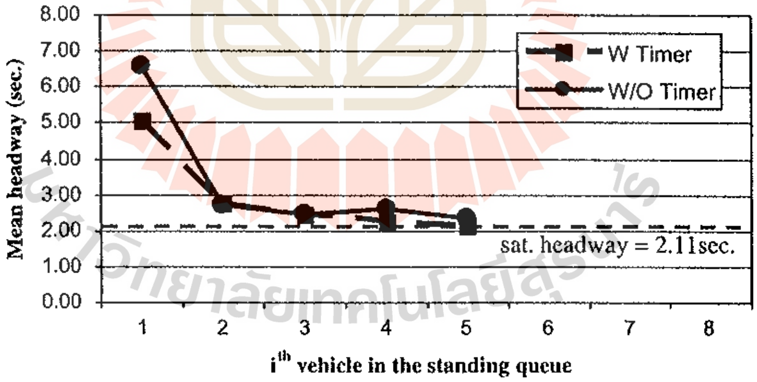
From the findings above, the countdown timers seem to improve the flow of the through movement during the green phase. Even though the timers have trivial impact on the saturation flow rate, the saving in SULTs contribute moderate improvement on the overall flow at signalized intersections. In this study, the countdown timers were found to reduce SULTs by 1.00–1.92 seconds per cycle, which can be translated into 0.5–1 extra vehicle/cycle. Given a cycle length of 151 or 230 s utilized in Bangkok, an hour comprises of 15.6–24 repeated cycles. Thus, the countdown timers can be reasonably expected to increase the throughput of the through movement by 8–24 vehicles/h per lane. The four-legged intersection with a total of eight through lanes (six lanes on the east–west approach plus two lanes on the north–south approach) can reasonably expect to accommodate up to 64–192 extra vehicles/h on the through movement of all approaches combined. Nevertheless, the



(a) Off-peak day time (10:00 – 15:00)



(b) Night time (20:00 – 22:00)



(c) Late-night time (22:00 – 02:00)

Fig. 2. Comparison of headway patterns of the first few vehicles in the standing queue.

benefits of countdown timers in flow improvement in other locations could be significantly different from Bangkok intersections depending on many locality factors. More studies are warranted to further investigate the impacts of countdown timers on queue discharge characteristics in a variety of sites, as well as for different turning movements, such as left-turns and right turns.

A ballpark estimation has shown that the benefits in terms of SUTL time saving would offset the capital costs of the countdown timer in a few years. The current hardware cost plus installation fee of a countdown display unit in the Bangkok area is approximately US$1715 (using an exchange rate of 35 baht: 1$US). With a saving in SULTs of 1.92 seconds per cycle per lane, the installation of a countdown timer would save a total of (1.92 s/cycle/lane × 3 lanes × 15.6 cycles =) 90 s in an hour, or 0.60 h/day. Assuming the average time cost of Bangkok commuters is approximately US$2.15/h, it requires slightly more than 3 three and a half years (3.66 years to be exact) for the SULT time savings to compensate for the capital cost of the equipment. Note that this approximation is for an approach with three through lanes, and does not account for the benefits for right-turn and left-turn movements.

It should be noted that this study only analyzed the vehicular flow benefit of the countdown timers. There are other major benefits to be considered, for example, the safety implication during the end of the green phase, and the psychological effects reducing drivers' stress at intersections with long cycle times. The road safety aspects have been previously investigated in the field, but still need further investigation to determine the effects across different regions and driving cultures. Even though it has not yet been studied, the psychological aspect is potentially the greatest benefit of the installation of the countdown timers, from the driver's point of view. Based on the author's experience, and personal communication with a range of people, drivers in Bangkok tend to appreciate the signal countdown timer because it provides timing information for the green onset. Drivers can utilize their time while waiting for the green phase more appropriately. Also, stress developed while waiting in the queue for an unknown of time is quickly dissipated by the numbers shown on the countdown timers. Therefore, a systematic analysis of the psychological benefits due to countdown timers is encouraged for future studies.

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ประวัตินักวิจัย

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ดร. ถิรยุทธ ได้เริ่มปฏิบัติงานครั้งแรกในช่วงปี พ.ศ. 2537 กับบริษัท ทีที แพลนนิ่งแอนด์ดีซายน์ จำกัด ที่กรุงเทพ เป็นระยะเวลาประมาณเวลา 1 ปี ก่อนที่จะไปเรียนต่อในระดับปริญญาโทและเอกที่ประเทศสหรัฐอเมริกา ภายหลังจบการศึกษาแล้ว ก็ได้ร่วมงานกับบริษัท TJKM จำกัด ใน San Francisco Bay Area รัฐแคลิฟอร์เนีย ประเทศสหรัฐอเมริกา เป็นเวลาเกือบ 4 ปี ได้รับตำแหน่งวิศวกรจราจรอาวุโสเป็นตำแหน่งสุดท้าย ก่อนที่จะกลับมาประเทศไทยเข้าร่วมงานกับบริษัท แพลนโปร จำกัด ในเขตกรุงเทพและปริมณฑล ในตำแหน่งวิศวกรจราจรอาวุโส เป็นระยะเวลา 1 ปีครึ่ง ก่อนที่จะมาเริ่มปฏิบัติงานในตำแหน่งอาจารย์ สาขาวิชาวิศวกรรมขนส่ง สำนักวิชาวิศวกรรมศาสตร์ มหาวิทยาลัยเทคโนโลยีสุรนารี ในช่วงปลายปี พ.ศ. 2548 ปัจจุบัน ดำรงตำแหน่งเป็นผู้ช่วยศาสตราจารย์ ประจำสาขาวิศวกรรมขนส่ง