Graz University of Technology

Institute of Highway Engineering and Transport Planning

Modelling Red Time Counters at Actuated Traffic Signals

DISSERTATION

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Mohsin BALWAN (M.Sc.)

Supervisor: Univ.-Prof. Dr.-Ing Martin Fellendorf, TU Graz

Reviewer: Assoc. Prof. Khaled Hamad

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Abstract

To improve traffic safety at signalised intersections, some cities apply timers indicating the remaining interval time. At pre-timed signals (fixed phasing) remaining times are predictable and can be visualised easily. At traffic responsive intersections, the actuated traffic signals become demand dependent and thus traffic counters indicating remaining red or green cannot be accurately predicted, thus citing the need to revisit the strategy to implementing the countdown timers. A signal countdown timer (SCT) provides pedestrians and drivers with a display of remaining time until a signal light changes its traffic control status. SCTs are used in many of the world's major cities to assist pedestrians crossing the road as well as drivers navigating the intersection. Many studies have shown positive impacts of SCTs in improving efficiency and safety of intersections. However, some cities have recently removed the devices which were only displaying remaining time for fixed-time signals.

The primary goal of this research was to develop a presentation method for actuated traffic SCT with a performance measure of the method. Also, the study investigated public opinion in the United Arab Emirates (UAE) toward the use of SCTs. In order to achieve these combined goals, two questionnaires were prepared. One questionnaire assessed the perception of drivers toward vehicle countdown timers (VCTs). The second questionnaire assessed pedestrian perception toward pedestrian countdown timers (PCTs). A total of 1,000 valid questionnaires were collected in May 2015, 500 from drivers and 500 from pedestrians. In-depth analysis studied the influence of characteristics of the respondents on their perception toward SCTs. Analysis showed that both drivers and pedestrians generally perceived SCTs positively.

As a part of this thesis, an algorithm has been developed and presented to use a prediction method and change the speed of countdown timers to suit the phase duration for signals in actuated mode. This algorithm has been tested in a simulated environment using the microsimulation software VISSIM in three different traffic demand scenarios to check the prediction performance. A simple method of red time interval prediction was proposed for signals running under actuated mode to evaluate the performance of the countdown timer algorithm. Not surprisingly, the simulation's results indicated the best prediction quality during peak periods since green times are usually maximised. Countdown timers with digits were not considered applicable in the case of actuated signals, so the timer design used in this research was a bar-and-circular type.

As a final step in the study, a method was developed to evaluate the technology and define an acceptable tolerance. Change in speed was the key to defining the evaluation method. To define acceptable speed changes, a questionnaire was prepared which included videos showing countdown timers with different speed changes. Online surveys were distributed through email to random groups including some

specialists in the field of traffic control. A total sample of 363 responses has been collected. Of those, 253 responses have been validated and analysed to define the accepted speed change. Questionnaire results, in general, showed that the characteristics of participants did not affect their observations and perceptions. The findings have been converted to the numerical format, and the results show that a 55% speed change could be acceptable for these types of countdown timers used with actuated signals.

In summary, the thesis concludes that presenting the remaining time at actuated signalised intersection can be solved by using the proposed countdown timer method used in this thesis.

Zusammenfassung

Um die Verkehrssicherheit an beampelten Kreuzungen zu verbessern, verwenden einige Städte Timer, welche die verbleibende Intervallzeit anzeigen. Bei zeitlich programmierten Ampeln (feste Phasen) sind die verbleibenden Zeiten vorhersagbar und können leicht visualisiert werden. Bei verkehrsabhängigen Kreuzungen werden die Ampeln bedarfsabhängig angesteuert und somit können die verbleibenden Rot- oder Grünphasen nicht genau vorhergesagt werden, was die Notwendigkeit zum Überdenken der Strategie für die Implementierung der Restzeitanzeige aufwirft. Eine Lichtsignalanlage mit Restzeitanzeige oder auch "SCT" (Englisch für Signal Countdown Timer) bietet Fußgängern und Fahrern eine Anzeige der verbleibenden Zeit bis eine Ampel ihren Verkehrssteuerungszustand ändert. SCTs werden in vielen großen Städten der Welt eingesetzt, um sowohl Fußgängern beim Überqueren der Straße zu helfen als auch Fahrern beim Befahren der Kreuzungen. Viele Studien haben die positiven Wirkungen von SCTs auf die Verbesserung der Effizienz und der Sicherheit von Kreuzungen gezeigt. Jedoch haben einige Städte jüngst die Geräte entfernt, die nur die verbleibende Zeit für Ampeln mit fester Zeit anzeigen.

Das primäre Ziel dieser Forschung war es, eine Darstellungsmethode für verkehrsabhängig gesteuerte SCTs zu entwickeln. Außerdem untersuchte die Studie die öffentliche Meinung in den Vereinigten Arabischen Emiraten (VAE) bezüglich der Verwendung von SCTs. Um diese kombinierten Ziele zu erreichen, wurden zwei Fragebögen vorbereitet. Ein Fragebogen bewertete die Wahrnehmung von Fahrern gegenüber Fahrzeug-Countdown-Timern (VCT, Englisch für Vehicle Countdown Timer). Der zweite Fragebogen bewertete die Wahrnehmung der Fußgänger gegenüber Fußgänger-Countdown-Timern (PCT, Englisch für Pedestrian Countdown Timer). Im Mai 2015 wurden insgesamt 1.000 gültige Fragebögen eingesammelt, 500 von Fahrern und 500 von Fußgängern. In einer eingehenden Analyse wurde der Einfluss von Merkmalen der Befragten auf ihre Wahrnehmung von SCTs untersucht. Die Analyse zeigte, dass sowohl Fahrer als auch Fußgänger die SCTs im Allgemeinen positiv wahrnehmen.

Als Teil dieser Arbeit wurde ein Algorithmus entwickelt und vorgestellt, um eine Vorhersagemethode zu verwenden und die Geschwindigkeit von Countdown-Timern an die Phasendauer für Ampeln im verkehrsabhängig gesteuerten Modus anzupassen. Dieser Algorithmus wurde in einer simulierten Umgebung unter Verwendung der Mikrosimulationssoftware VISSIM in drei verschiedenen Verkehrsszenarien getestet, um die Vorhersageleistung zu überprüfen. Es wurde ein einfaches Verfahren zur Vorhersage des roten Zeitintervalls für im verkehrsabhängig gesteuerten Modus betriebene Ampeln vorgeschlagen, um die Leistung des Countdown-Timer-Algorithmus zu bewerten. Es war nicht überraschend, dass die Ergebnisse der Simulation die beste Vorhersagequalität in Spitzenzeiten aufwiesen, da Grünzeiten normalerweise maximiert werden. Countdown-Timer mit Ziffern wurden im Fall von

verkehrsabhängig gesteuerten Ampeln als nicht anwendbar erachtet, so dass das in dieser Untersuchung verwendete Zeitgeberdesign eine Balken- und Kreisform besaß.

Als letzter Schritt in der Studie wurde eine Methode entwickelt, um die Technologie zu bewerten und eine akzeptable Toleranz zu definieren. Geschwindigkeitsänderungen waren der Schlüssel zur Definition der Bewertungsmethode. Um akzeptable Geschwindigkeitsänderungen zu definieren, wurde eine Umfrage vorbereitet, die Videos enthielt, welche Countdown-Timer mit unterschiedlichen Geschwindigkeitsänderungen zeigten. Online-Umfragen wurden per E-Mail an zufällige Gruppen verteilt, darunter einige Spezialisten im Bereich der Verkehrssteuerung. Eine Gesamtstichprobe von 363 Antworten wurde erhoben. Von diesen wurden 253 Antworten validiert und analysiert, um die akzeptierte Geschwindigkeitsänderung zu definieren. Die Umfrageergebnisse zeigten im Allgemeinen, dass die Eigenschaften der Teilnehmer ihre Beobachtungen und Wahrnehmungen nicht beeinflussten. Die Ergebnisse wurden in das numerische Format umgewandelt, und die Ergebnisse zeigen, dass eine Geschwindigkeitsänderung von 55% für diese Arten von Countdown-Timern akzeptabel sein könnte, die mit verkehrsabhängig gesteuerten Ampeln verwendet werden.

Zusammenfassend kommt die Arbeit zu dem Schluss, dass die Darstellung der verbleibenden Zeit bei Kreuzungen mit verkehrsabhängig gesteuerter Beampelung mittels der in dieser Arbeit vorgeschlagenen Countdown-Methode gelöst werden kann.

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1. Introduction

1.1. Background

In 1950, 30% of the global population was living in urban areas. This percentage jumped to 55% in 2018, and it is predicted to reach 68% in developing countries and 90% in developed countries by 2050. That is equal to nearly 3 billion urbanites, with cities and towns in Asia and Africa registering the most prominent growth (UNDESA, 2018). Thus, the urban areas in most countries are projected to take all the expected population growth over the next four decades. This urbanisation growth has a significant effect on traffic congestion, and traffic engineers must think about useful and practical mitigation for future congestion.

Traffic congestion costs have increased dramatically in the last decades (Schrank, Lomax and Eisele, 2011), where the cost of the congestion was $21 billion in 1982 and reached $101 billion in 2010. The report predicted the cost to be $175 billion by 2020 in the US only. In Dubai, the annual loss was almost 4.6 billion according to Khaleej Times on 18th Dec 2016. Considering these anticipated costs, decision makers, city governments, and planners have tried many ways to reduce the congestion cost. Some options are building new roadways or widening existing roadways, introducing new transportation modes, implementing intelligent transportation systems, and others. Those strategies achieve deferent mitigation levels in resolving congestion. Most of those mitigation strategies come with huge price tags.

It is a long-recognised truth that signal improvement is one of the most useful and cost-effective methods to reduce congestion in urban areas (Meyer *et al.*, 2002). Traffic signals become an essential device for transportation engineers, especially with the rapidly growing of a number of vehicles within urban areas which lead to more congestion and accidents. Traffic intersections are a common and vital part of the roadway system. By using the intelligent transportation systems such as traffic signals, those traffic intersections can operate more efficiently without spending much money on building or widening the roads. Approaching congestion mitigation through signalisation addresses not only the cost concern but also any land shortages and side effects of construction periods.

Many studies have been done to improve the efficiency of traffic signals. As a result, some extra equipment has been attached to signals to increase the safety and comfort for drivers and pedestrians. One of those additional parts is a signal countdown timer (SCT). SCTs were introduced in several cities to increase safety and comfort as a result of the additional information provided. An SCT is a device which shows the remaining time of the ongoing signal phase as a number or a graphical display. This device notifies drivers or pedestrians of the exact time when the upcoming phase change is going to occur. In the USA, SCTs are widely used for pedestrian phases to assist disabled or elderly pedestrians, as well as adults accompanying small children (Keegan and O'Mahony, 2003). SCTs are used to help drivers to make better-informed decisions to stop their vehicles or cross the intersection's stop line in some other countries. Therefore, the use of SCTs mainly divides into two categories based on the target users: SCTs used to inform vehicle drivers and those used by pedestrians.

Although SCTs have positive impacts, many Asian cities favoured traffic control efficiencies over the SCTs for gains in safety benefits. These cities elected to uninstall their systems due to the systems' constraints of pre-timed traffic signals that are generally less efficient in moving traffic compared to actuated signals (Chen, Zhou and HSu, 2009). SCT use with actuated traffic signals is considered more challenging than its use with pre-timed signals. In pre-timed operation, an SCT displays the remaining fixed time, which is generally not available in actuated signals. In actuated signals, the time allocated to each phase varies based on traffic demand which makes it difficult to predict the time to show in the SCT. It is rare to find studies integrating the SCT with actuated signals. Most of the studies related to SCTs were conducted with pre-timed signal control.

This study's primary objective was to propose and evaluate a new way of presenting the interval remaining time for traffic signals in actuated mode.

1.2. Motivation

Although SCTs have positive impacts, cities using actuated signalisation have found difficulty in reconciling SCTs to signal operation. To achieve safety benefits, these cities often have elected to uninstall SCTs and implement other options. In pre-timed operation, an SCT displays the remaining fixed time, which is generally not available in actuated signals because timing varies based on traffic demand. Few studies have researched SCT operation with actuated signals. Over 75% of the traffic signals in Sharjah are actuated traffic signals, and cities within the Gulf Cooperative Council region are actively considering SCT installation. With the constraint of changing traffic signals to actuated timing, it may not be possible to maintain SCTs.

This study's main goal was to propose a new method of presenting the remaining time in actuated mode. Also, the study investigated public opinion in the United Arab Emirates (UAE) toward the use of SCTs. To achieve these combined goals, the following set of objectives was defined:

- Investigate public opinion about SCT use in UAE by preparing and distributing two questionnaires. While the first one was designed to assess the perception of drivers toward vehicle countdown timers (VCT), the second one was designed to assess the perception of pedestrians toward pedestrian countdown timers (PCT).
- Develop an algorithm to present the remaining interval time which works under actuated signal mode.
- Evaluate the proposed method using traffic flow simulation software VISSIM as a real-world case study.
- Develop performance measures for the algorithm by evaluating the perception of the public on the proposed strategy for implementation of vehicle actuated SCT's.

1.3. Structure of the study

This dissertation is organised as follows. Chapter 2 gives an introduction about traffic signals and their main elements, including warrants and terminology. The chapter provides details about signal control methods and describes vehicle-actuated signals. It explains the actuated control principles which make up one of the leading aspects of this study. Signal operational objectives and performance measures are discussed in Chapter 2 as well. The last section of the chapter describes details of countdown timers.

Chapter 3 provides a literature review of vehicle and pedestrian countdown timers. The chapter focused on advantages and disadvantages of countdown timers regarding each type of signal interval and concluded that red interval countdown timers have positive impacts more often than green interval countdown timers.

Chapter 4 presents the statistical results of the surveys conducted in this study with drivers and pedestrians regarding attitudes toward vehicle and pedestrian countdown timers. The chapter is presented in two main sections: statistical analysis of the driver survey, and statistical analysis of the pedestrian survey. Each section describes in detail the analysis results by using hypothesis tests and comparisons.

Chapter 5 describes an algorithm designed in this study to use the prediction method and change the speed of a countdown timer to suit the phase duration in actuated mode. The algorithm has been tested under a simulation environment using the microsimulation software VISSIM. Results from the simulation were evaluated to check algorithm performance. Chapter 5 presents findings and proposes a simple method of red interval prediction for signals running under actuated mode to evaluate the performance of the countdown timer algorithm. The outcomes described in the chapter are used to create a sample case for Chapter 6.

Using the outcomes described in Chapter 5, Chapter 6 presents an evaluation method for countdown timers examined in this study. The evaluation method described in this chapter is a questionnaire which includes countdown timer simulations in different scenarios. The results presented in the chapter derived from the questionnaire and were analysed to define an acceptance level for proposed countdown timers.

Chapter 7 summarises the results and concludes the study providing recommendations for future studies.

2. Traffic signals

2.1. Introduction

“Necessity is the mother of invention.” That phrase covers many inventions, and traffic signals are no different from any invention developed out of necessity. Humans had tried to figure out solutions to their problems as and when they arrived, and traffic has arrived in droves.

Traffic mainly constitutes pedestrians, cars, buses, trains, public vehicles, two-wheelers, and other conveyances that we have access to as modes of transportation. Traffic lights are a method to control traffic, avoid road collisions, and manage traffic without confusion or congestion. However, the control and functioning of traffic lights have seen numerous changes with technological upgrades. Dating back to 1800s in London, due to issues of road safety from steam-driven vehicles, a “locomotive act” was adopted in 1836. Parliament House in London saw the first traffic lights in 1868, and traffic signals were first used for controlling trains. Early on, automobiles were not even invented and gas-lit lights were used to manage horses and pedestrian road safety (Pašagić and Ščukanac, 1998).

The industrialisation period increased traffic, and people felt the need or ability to travel. With the invention of automobiles, the real face of traffic came into broad daylight. Lester Wire, an American policeman, originated electric traffic lights in 1912. Cleveland, Ohio, saw the first traffic lights appear in use in 1914 at Euclid Avenue and the corner of 105th. In 1920, William Potts in Michigan invented the first four-way, three-coloured traffic lights.

The first international agreement on road and vehicles traffic was conducted in 1909 in Paris (Pašagić and Ščukanac, 1998). Emphasis was placed on setting up globally understandable and uniform traffic signals for all nations. No written signs were allowed. Only light symbols were marked for controlling the traffic so that illiterates and foreigners could understand and follow directions (Pašagić and Ščukanac, 1998).

During the initial years of automobile penetration, people did not feel much need to learn traffic signs and signals. It was only after personal vehicles came into popularity that people faced problems such, not able to be being able to locate their way or contending with collisions. Today traffic signal control is a vital research topic, and new experiments are being carried out each day to develop the optimal solution to resolve the problem of wasted time and crashes on the road.

In urban roadway infrastructure, traffic control systems are the most significant element. Traffic signals control the most inherent trait of humans, which is to move or be still, as well as providing direction on other driving rules. These days, traffic control research also includes studying the behaviour and psychology of drivers and pedestrians (Mcshane, 1999).

Roadways are sectioned into several divisions in the form of lanes, intersections, junctions, traffic signals, etc. Each of these divisions is allotted a particular speed limit depending upon the volatility of the area. Rules, signboards, and limits are set for specific areas, while minor areas may be left to the driver's common sense and ability to drive. In the absence of traffic signals, congestion, especially at junctions, may result in road collisions that prove to be lethal for humans.

Now, with the computerised systems, we can consider advanced signal control methods. Systematic approaches and strategies are being researched to have the least wait time on signals, and intelligent controlling of signals through programmable control offers options. Significant research work is going on in this area to plan out the best suitable approach to handle traffic controls. More efforts are being put into reducing wait time because it increases delays, jeopardises safety, and causes environmental pollution (Papageorgiou *et al.*, 2003).

New electronic sensors and microcontrollers are promising solutions for managing traffic better and are considered to be our best shot for the adoption of a zero-accident goal on roads. Traffic analysis software, distance detection software, and timing controls through various state-of-the-art technologies are seen as the future of traffic signals. The technology is incorporating methods to reduce human error to negligible levels and use the precision of machine learning to control traffic signals through programmable logic.

In conclusion, traffic signalisation plays an essential role in sorting out travel plans and thereby makes our lives safer and freer of stress. Traffic lights and signs may have sophisticated controlling mechanisms in the future, but their need and fundamentals will not cease to exist anytime soon.

2.1.1. Traffic signal warrants

Researchers have come up with nine warrants that must be met (one or more) before any decision can be made on installing traffic signals at intersections (MUTCD, 2009). The traffic signal warrants provide engineers with decision-making insights when it comes to installation of traffic signals at intersections. However, that alone would not justify installation; instead, a full-scale engineering study should be conducted, justifying the need for a new installation for enhanced safety and operation procedures at the intersection (MUTCD, 2009).

Warrants should be considered as "one of the determinants," not as "absolute determinants." Hence, proving the validity of a warrant might not single-handedly justify the necessity of a traffic control device. Engineers should use their judgment while making the final decision. The nine warrants are:

- Warrant 1, Eight-Hour Vehicular Volume
- Warrant 2, Four-Hour Vehicular Volume
- Warrant 3, Peak Hour
- Warrant 4, Pedestrian Volume

- Warrant 5, School Crossing
- Warrant 6, Coordinated Signal System
- Warrant 7, Crash Experience
- Warrant 8, Roadway Network
- Warrant 9, Intersection Near a Grade Crossing

Warrant 1: Eight-hour vehicular volume

Two conditions might perfectly fit the eight-hour vehicular volume warrant. First, massive traffic load at the intersection, which might be the main reason behind considering such a signal. Second, the traffic on the major street is so dense that vehicles from the minor street face excessive delays while crossing the intersection (MUTCD, 2009). There might be instances where applying the solution to the first condition and the second condition might still not be sufficient. In such cases, a combination might be considered. In this approach, both conditions can be met while also reducing the volume threshold for such control signal installation. While eight-hour volumes of traffic will be similar within each condition to what was before the combination, the individual volume may not be the same for both cases.

Warrant 2: Four-hour vehicular volume

When the volume of traffic crossing an intersection is the main reason to install a traffic light at a junction, this warrant might be the perfect fit for such instances.

Warrant 3: Peak hour

There might be intersections where vehicles on the minor street face unexpected delays due to heavy traffic loads on the major street during the busy hours of the day. Here, this peak-hour warrant might be applied, but this warrant is an unusual one and should only be applied if there is an industrial zone or office areas within the vicinity (MUTCD, 2009). Furthermore, if the engineering survey proves the need for signal installation and this warrant criterion is met, installation of traffic signals should be done and operated in a flash mode.

Warrant 4: Pedestrian volume

There might be major roads with excessive traffic where pedestrians face difficulties in crossing the road. These types of intersections are prime candidates for pedestrian volume signals. However, it must be noted that if the nearest traffic control signals are located within 300 feet of the chosen location, then this warrant should not be applied (MUTCD, 2009).

Warrant 5: School crossing

There are intersections which are crossed mainly by school children instead of vehicles. Hence, in such cases, this warrant for traffic control signals could be applied.

Warrant 6: Coordinated signal system

With a required traffic control signal spacing of equal or more than 1000 feet, this warrant might be considered at intersections where proper platooning of vehicles is necessary and cannot be achieved otherwise (MUTCD, 2009).

Warrant 7: Crash experience

There are intersections where frequent and severe crashes take place among vehicles, bicycles, and pedestrians. In those places, this crash experience warrant might be applied.

Warrant 8: Roadway network

To organise the scattered traffic flow within a roadway network, this warrant might be considered at some intersections.

Warrant 9: Intersection near a grade crossing

Only when all the other eight warrants fail to meet the criteria and all other alternatives are discarded, this warrant should be put into practice. Intersections that contain grade crossings on all approaches that are controlled by either a STOP or YIELD sign are prime candidates for this final warrant (MUTCD, 2009).

2.1.2. Traffic signal terminologies

Each signal control contains main elements which are used to design the signal program and logic. Those elements are the essential infrastructure parts of the signal control and are described in the following paragraphs.

Interval

The duration of time where a traffic signal indication does not change state (red, yellow, green, walk, and don't walk) (Koonce *et al.*, 2009).

Signal aspect

Each light in the signal head can be called an aspect. Most vehicle traffic lights contain three aspects: green, amber, and red. The most pedestrian signal head contains two aspects: green and red; or walk and don't walk, which are shown in the green and red colour.

Signal group

A signal group is a set of signal heads connected and working simultaneously. They should receive the same signal indication in each phase for the whole signal timing program. Each signal group gives a particular movement to have the right of way simultaneously. See **Figure 1.**

Signal head

The signal head contains the signal aspects. It can be installed on a pole on the roadside or a cantilevered post as shown in **Figure 2**. More than one head can be fixed on the same pole even if they are not working simultaneously.

Phase

The signal phase is a set of signal groups which work during the same time interval and do not have a conflict. The Manual of Uniform Traffic Control Device (MUTCD) defines a phase as “the right-of-way, yellow change, and red clearance intervals in a cycle that is assigned to an independent traffic movement.” See **Figure 3**.

Cycle

A cycle contains the complete sequence of signal indications (Koonce *et al.*, 2009). Each cycle is repeated during the day. The sequence and timing can be changed from cycle to cycle based on the logic. Each cycle contains the total time of the phases and inter-greens.

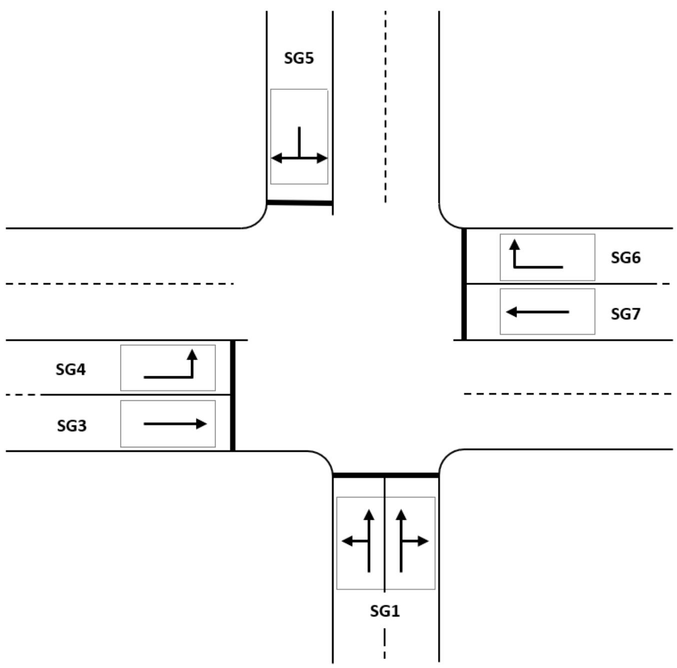


Figure 1: Signal groups in a four-leg intersection

Phase sequence

Phase sequence indicates the order of the phases in a cycle period, as shown in **Figure 3**. The order can be altered based on the logic used in the signal control. For example, public transport priority logic can change the phase sequence and jump to the phase which has the public transport mode, thus giving priority to a bus or tram.

Figure 2: Signalised intersection in Dubai, UAE

Inter-green time

The time between the end of the green interval in a signal group and the onset of the next green interval is the inter-green time. It is used and designed to clear the intersection from vehicles which enter the intersection at the end of the green intervals. See **Figure 4**.

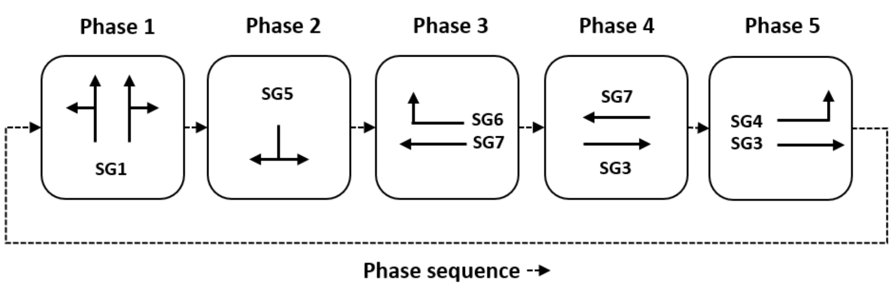


Figure 3: Signal phases and phase sequence

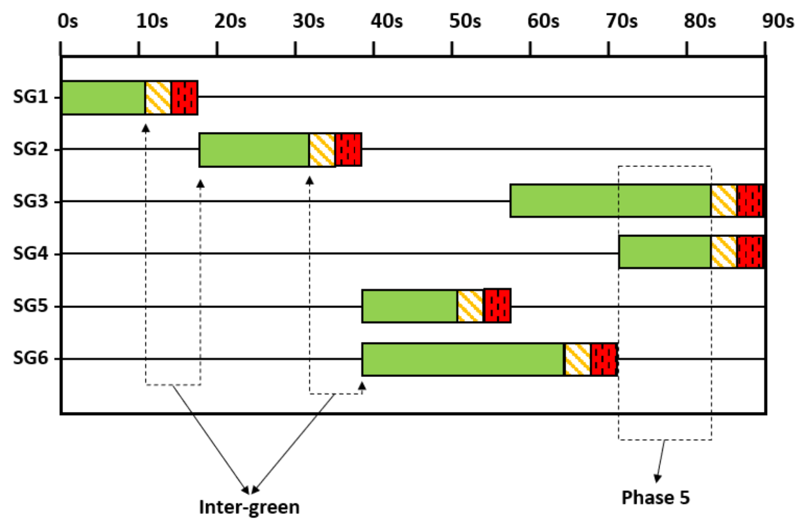


Figure 4: Signal timing diagram showing the inter-green and signal groups running in the same phase

Green time

The duration of the green indication in seconds for a given movement. It is the time interval when the vehicles are allowed to cross the intersection.

Effective green time

The total green time which can be used efficiently. In each green interval, there is lost time at the beginning and the end of the yellow interval. The effective green time is the time between those two losses, as shown in **Figure 5**.

Saturation Flow

The saturation flow rate crossing a signalised stop line is defined as the number of vehicles per hour that could cross the line if the signal remained green all of the time. It is not practical to measure this quantity directly in the field because the signal does not usually remain green for more than a minute or so on each cycle. The units of saturation flow rate are “vehicles per hour of green” which is sometimes expressed on a per-lane basis as “vehicles per hour of green per lane”. The saturation flow rate may be derived from the steady-state headway, which is defined as the average elapsed time between the passage of successive vehicles over the stop line in the same lane.

The Highway Capacity Manual (HCM) suggests recording the time of passage of the fourth and tenth vehicles over several cycles to determine this value. This assumes that the initial queue at the start of green is at least ten vehicles long. The first few vehicles are excluded because of the transient effect of starting up the queue. Vehicles beyond the tenth are excluded because they may represent the arrival rate instead of the departure rate. A typical value for the steady state headway is approximately 2 seconds per vehicle in each lane. In other words, each vehicle requires 2 seconds of the available green time. This yields a typical saturation flow rate of approximately 1800 vehicle per hour. The basic model of saturation is illustrated in **Figure 5**.

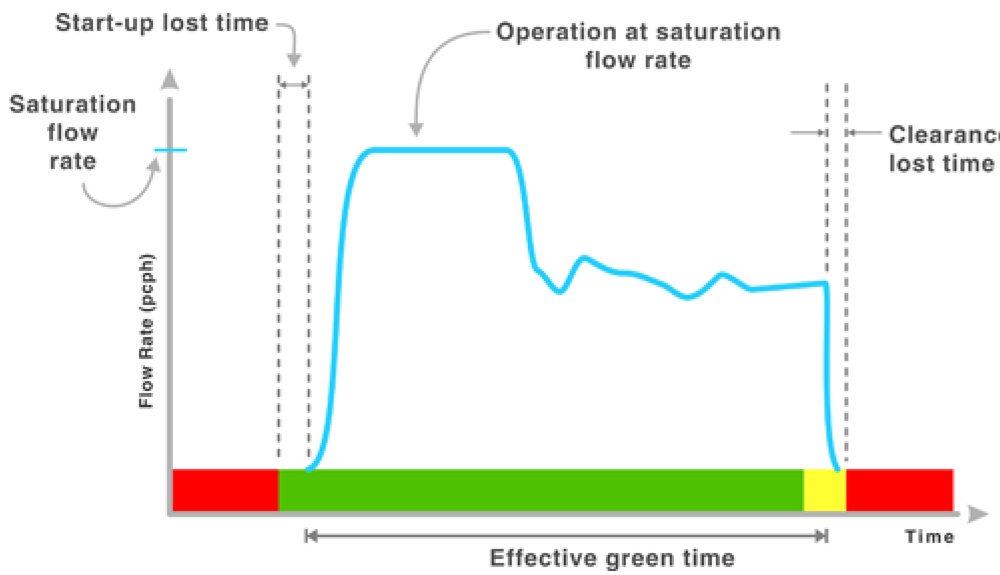


Figure 5: Basic model for saturation flow (Koonce *et al.*, 2009)

Dilemma zone

One type of dilemma zone may be observed among vehicles when drivers decide whether they can stop adequately before the red signal appears. Alternatively, drivers might fail to proceed through the intersection without violating the red signal which can be the first type of dilemma zone. On the other hand, the type-2 dilemma zone is observed when the yellow signal is showing, and drivers cannot make up their minds on whether to proceed through or stop. See **Figure 6**.

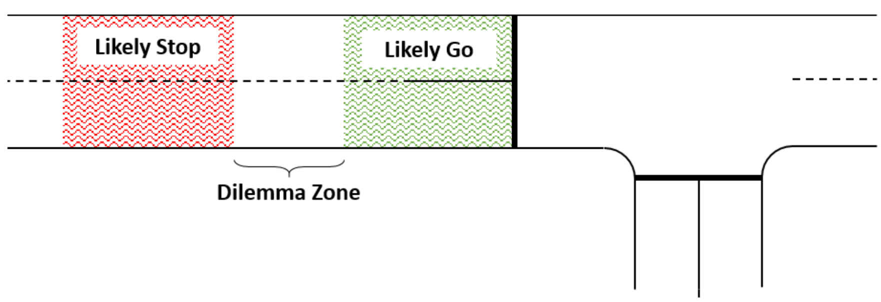


Figure 6: Dilemma zone

Headways

The term headway refers to the time measured from the front axle or bumper of two successive vehicles past a point on the street.

Cycle length

The time required to show a phase sequence entirely is called a cycle length. It is one of the main elements which affects intersection capacity. The length of the cycle is calculated based on the time needed to serve all movements, adding to that the lost time. It is essential to design the cycle length to sufficiently release all standing vehicles and pedestrians at the intersection with minimum waiting time. There are many aspects which affect the selection of the optimum cycle length. At non-connected signal intersections which work under actuated modes, the cycle length will change depending on the immediate demand from cycle to cycle. At pre-timed intersections, the cycle length is calculated based on the data collected from the intersection of the volumes. High volume will need more time, which leads to longer cycles. However, the long cycle time is not recommended, otherwise delay time for the vehicles and pedestrians will be more.

Webster's graph shows how the delay is increased after a specific time as shown in **Figure 7**. The optimum cycle length can be calculated using the following Webster and Cobbe equation:

$$C = \frac{1.5L + 5}{1 - Y}$$

where:

C = optimum cycle length (sec)

L = total lost time (sec)

Y = critical lane volume divided by the saturation flow, summed over the phases.

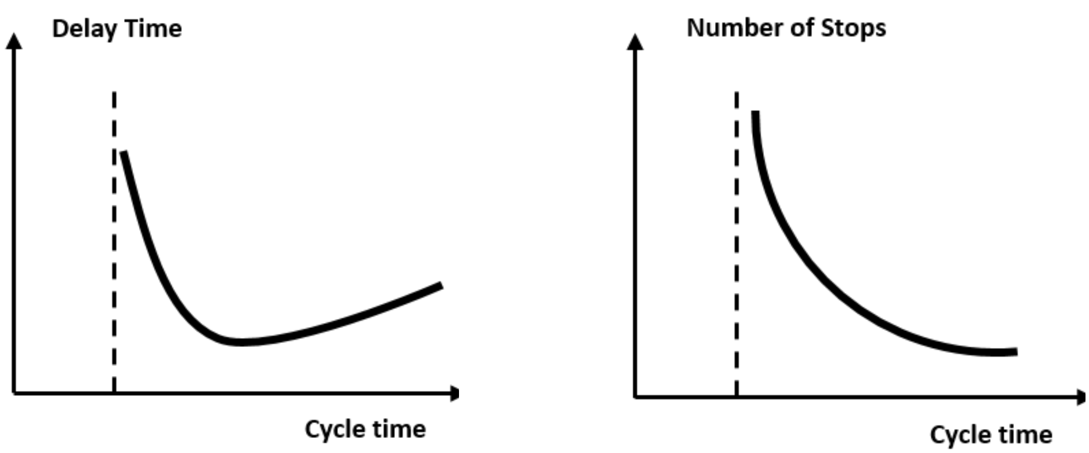


Figure 7: Cycle time and number of stops versus delay time (Boltze, 1988)

Safety is another factor affecting the cycle length design. Low speeds and short cycle lengths ensure a safer environment for pedestrians (Koonce *et al.*, 2009). There are many basic signal timing parameters used in designing the proper timing for a signalised intersection. Some parameters used in all types of signal control modes are parameters such as red clearance, yellow change, minimum green, etc. In this study, the conditions at isolated intersections have been studied, and the necessary parameters for uncoordinated signals will be discussed in detail. As per (Arroyo *et al.*, 2015) two basic parameters are yellow change and red clearance, described in the following paragraphs.

Yellow change

In this interval, the users are warned about the time changing from green interval to red or from red to green, which is used in some countries such as Austria or Germany. The duration of the yellow interval depends on the site condition and design speed. The yellow change interval should last approximately 3 to 6 seconds, where a higher-speed approach gets a longer yellow interval (Arroyo *et al.*, 2015). It can be calculated using the following equation. The primary purpose of the equation is to ensure proper time for a safe decision to stop or proceed.

$$Y = t + \frac{1.47v}{2(a + 32.2g)}$$

where

Y = yellow change interval (seconds)

t = perception-reaction time to the beginning of a yellow interval (seconds)

v = approach speed (miles per hour [mph])

a = deceleration rate in response to the beginning of a yellow interval (feet per second per second)

g = grade, with uphill positive and downhill negative (per cent grade/100) (feet/feet)

Red clearance (All red)

The period when all movements are getting red status is called red clearance. It is used to clear the intersection of vehicles and pedestrians and is optional in signal timing parameters. The designer should make sure a red clearance interval is needed at an intersection before including it because it can cause significant lost time if not needed. The geometry and design speed are the two main parameters affecting the duration of the red clearance interval (Arroyo *et al.*, 2015).

2.1.3. Signal control methods

To manage traffic congestion, having a well-managed signal control policy in place is of paramount importance. There are three different modes to control the traffic signal: pre-timed (fixed-time), actuated mode, or a mix of both and adaptive traffic control (Mathew, 2014). Fixed-time is used in most cities where after a specific duration some intervals are fixed. On the other hand, actuated signals mainly identify the presence of vehicles or pedestrians at the intersection and respond accordingly. Actuated signals contain detectors that can determine the presence of vehicles or pedestrians within the vicinity and change the interval time based on gathered information. Moreover, in addition to an alternation in green times and each cycle length, these controllers can change the sequence of phases.

Adaptive traffic control systems are the latest addition to a long list of controllers designed to manage street intersections. They calculate the amount of traffic within the area of an intersection, measure the signal times and implement them, thus resulting in reduced delays and shorter travelling times. Furthermore, adaptive traffic control systems ensure that while travelling a single route a vehicle gets green signals at every intersection, which is called a green wave. Traffic delays can be significantly reduced just by using the adaptive traffic control system with the help of vehicle-actuated signalling solutions. However, these systems are highly involved in nature and require expert handling since vehicle-actuated signal timing must be implemented correctly. The Sydney Coordinated Adaptive Traffic System (SCATS), Split Cycle Offset Optimization Technique (SCOOT), Balancing Adaptive Network Control Method (BALANCE), and Real-time Hierarchical Optimized Distributed and Effective System (RHODES) are variants of the adaptive traffic control system which are already in practice in many developed countries. In the later sections of this report, the principles and relevant features of vehicle-actuated signals will be discussed and reflected upon.

2.1.4. Vehicle-actuated signals

When a vehicle approaches an actuated intersection, it sends activation signals to a controller that in turn determines the phases or traffic movements that need to be serviced. Detectors are placed within intersections and approaches that can respond to demand and send information to the controller. The controller collects all the information from detectors, mixes and matches among them, and determines the aspects of signal timing that need to be altered on each cycle. The timing of the signal largely depends on the traffic flow and demands. Actuated controllers might accommodate variable phase sequences, green times, and cycle length (Mathew, 2014).

Advantages of actuated signals

There are several benefits to actuated signals. Some of the benefits mentioned by (Mathew, 2014) are:

- If timed correctly, actuated signals can reduce the delay.
- If there are fluctuations in the traffic flow, the signals can be optimised automatically.
- Actuated signals increase capacity.
- Actuated signals can be programmed to work even under low volume conditions.
- Actuated signals are best suited for multiple-phase intersections.

Disadvantages of actuated signals

There are several downsides to actuated signals as well. (Mathew, 2014) lists:

- Installation cost is very high compared with fixed-time signals.
- They are complex and thus require frequent maintenance.
- Continuous monitoring is needed to ensure the signal is working properly.
- In cases of regular traffic demand patterns, the efficacy of actuated signalling drops significantly.

Types of actuated control

There are three types of actuated control discussed in this section:

- Semi-actuated control
- Full-actuated control
- Volume-density control

a) Semi-actuated control

When there is a major street with consistent traffic flow intersected by smaller streets with limited traffic flow, a semi-actuated controller is used most efficiently. All detectors are placed on the minor streets, as shown in **Figure 8**, and there will always be green on the major street until traffic is detected on the smaller street (Mathew, 2014). The signal will only change if there is a call from a detector on the other side. In semi-actuated controllers, the minimum green interval is reserved for the major phase only (Mathew, 2014). Unless the side street shows a call for service, the green interval will remain indefinitely on the main street. When the green signal is displayed on the main street for a long enough time, and there is no vehicle to process anymore, the side street will show the green signal to process its vehicles. Point detectors are preferred choices here, and they are placed either in upstream or stop line locations (Mathew, 2014).

Advantages:

- Semi-actuated control is a perfect fit for a coordinated signal system.
- In comparison to fixed-timed control, during light traffic on major roads, it can save time and reduce delay.
- Detectors are not reserved for the major roads, and thus system efficiency does not depend on the success of these detectors.
- Whenever possible, green will show on the main street, decreasing congestion.

Disadvantages:

- Maintaining the system requires more training when compared to pre-timed controls.

- Instead of major approaches, detectors are placed on minor approaches that require continuous monitoring and maintenance.
- The excessive delay might occur in major road movements if there is a problem with setting up the maximum green and passage time parameters correctly.

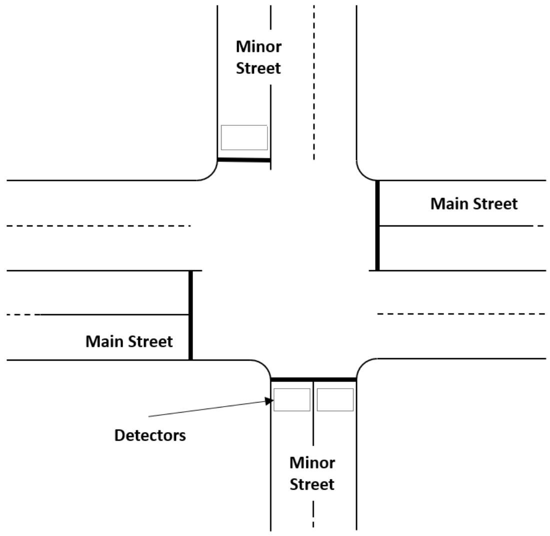


Figure 8: Semi-actuated detection's location

b) Full-actuated control

When a major street intersects with another street that has similar traffic volume, then a full-actuated controller will be used. Detectors are placed on all approaches (see **Figure 9**), and all other determinants such as green allocations and phase sequence are subject to change. Full-actuated control is ideally suited for two-phase or multi-phase operations. There will be a preset initial interval within each phase. Those phases will be constructed sequentially. For each actuation, a preset unit extension will be used to extend the green interval. There will be a maximum limit beyond which the green interval cannot be extended. Similarly, to a semi-actuated controller, point detectors should be used in all cases at two locations, namely the upstream location or the stop line.

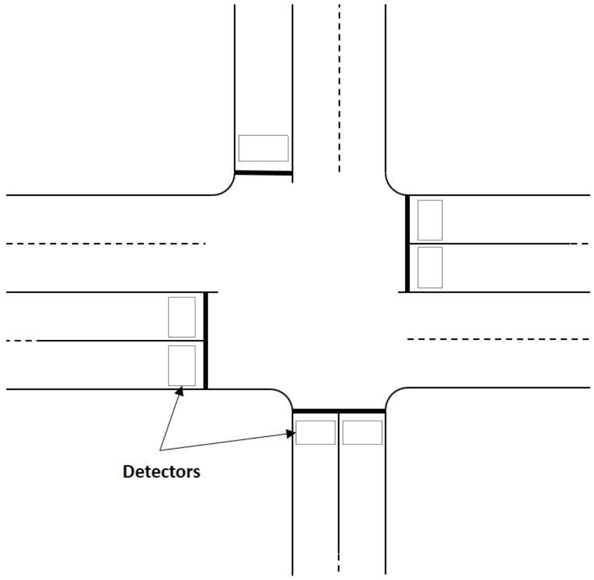


Figure 9: Fully actuated detectors' location

Advantages

- Full-actuated control is highly effective in reducing time delay in comparison to pre-timed control since it can respond to traffic patterns and modify timing accordingly.
- Since traffic patterns are calculated and analysed in advance by collecting data from the detectors, cycle times can be allocated based on those collected data.
- When there is no call for service, the whole phase can be skipped altogether, and the unallocated time could be used in another phase.

Disadvantages

- Despite all its advantages compared to other control system types, high initial costs might be a downside consideration.
- Full-actuated control might result in vehicles being stopped due to green time not being held for long enough for upstream platoons.

c) Volume-density control

Volume-density control is quite similar to full-actuated control but contains extended features. While full-actuated control is used for streets with steady traffic, volume-density control is used for intersections with considerable volume fluctuations (Mathew, 2014). Intersections with highly unpredictable traffic fluctuations are best suited for volume-density controllers. Also, intersections, where vehicles approach at speed greater than 45 mi/hr, are generally reserved for such controllers (Mathew, 2014). Furthermore, volume-density controllers are used along with area detectors, where detectors are placed on all different approaches. However, for this system to perform efficiently, it needs to receive information regarding the vehicle and traffic conditions well in advance. For this reason, detectors are usually placed well ahead of the intersection in all approaches.

2.1.5. Actuated-control principle

The execution of actuated phase control depends on three critical settings: minimum green, maximum green, and unit extension (Mathew, 2014). When initiated within the phase, the green is expected to be similar to the minimum green period in length. Furthermore, the minimum green is divided into two portions, namely the initial portion and the extended portion that must be equal to a one-unit extension. Also, if any call is received while executing the initial portion of the minimum green, there is no need to add additional time since there will already be enough time for the minimum green to cross the stop line. On the other hand, if any call is received during the extended portion, then additional seconds equal to the unit extension are added. It must be noted that those extra seconds should come from actuation time or call. To prevent unused green times to accumulate within the total green period, those seconds are not added to a previous unit extension. The green extension time will stop if reached to maximum green time or a unit extension expires before an additional actuation (Mathew, 2014).

Minimum green

The purpose of the minimum green interval is to satisfy driver expectancy, provide enough time for pedestrians to cross the street, and clear the traffic queue. Type of vehicles and users may affect the duration of the minimum green time. A vehicle such as bicycles, large trucks, and public transit take more time to start moving and clear the queue. Minimum green can affect traffic safety if it is too short and not meet driver or pedestrian expectation, increase the chances of rear-end accidents, and increase the number of red-light violations (Arroyo *et al.*, 2015). As per (Koonce *et al.*, 2009) the minimum green time can be between 2s to 15s. New controllers can adjust and allocate a proper minimum green time based on information collected from sensors. The following equations can be used to determine the minimum green with assumptions of start-up lost time of 3 seconds and headway time equal to 2 seconds to clear the intersection:

$$G_q = 3 + 2n$$

where

G_q = minimum green duration for queue clearance (seconds)
n = number of vehicles between stop bar and nearest setback detector in one lane

$$n = \frac{d}{L_v}$$

where

d = distance between the stop bar and the downstream edge of the nearest setback detector (feet)
L_v = length of the vehicle (feet), *set at 25 feet*

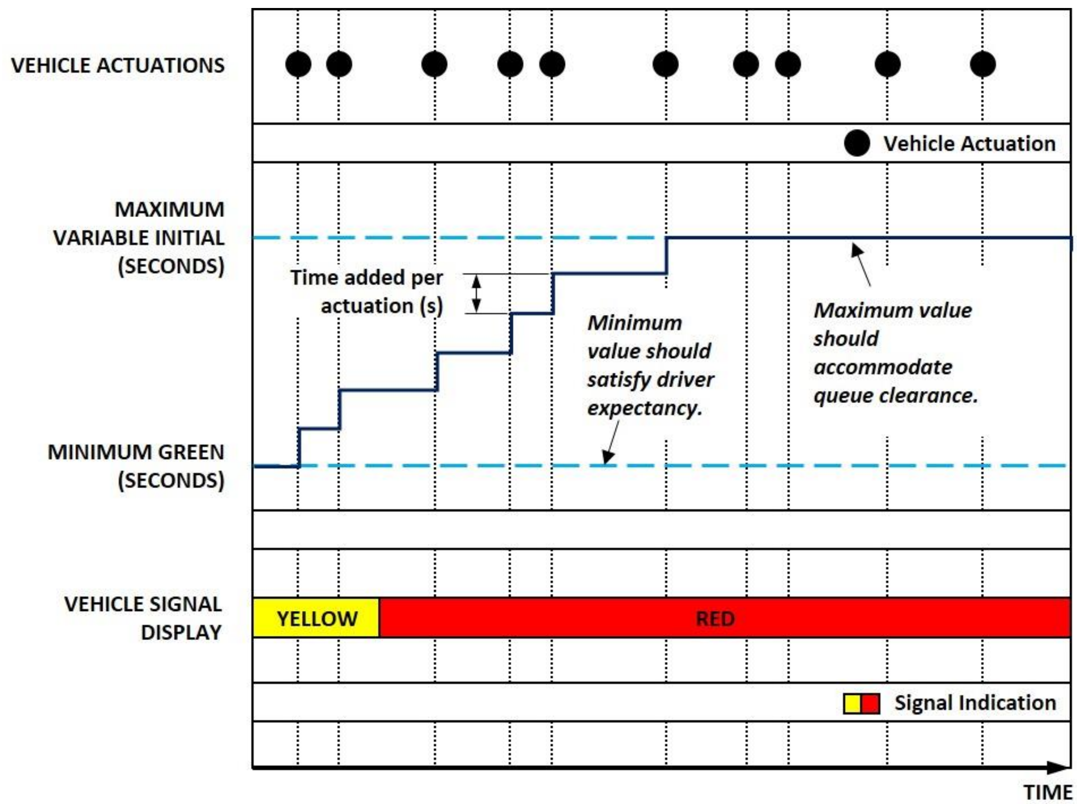


Figure 10: Variable initial (Arroyo *et al.*, 2015)

Maximum green time

The maximum green interval given for a movement to clear the queue can be changed several times per day based on demand. It is mainly dependent on the volume and time needed to ensure clearance of the traffic queue. A value which is too long can cause a longer delay for the other movements. In the case of detector failure, the green interval reaches the maximum green even if no vehicle passes which causes more delays. At the same time, it keeps the green interval within a specific value to ensure minimum lost time in the case of detector failure. Typical values of maximum green can be between 14s to 70s based on phase and facility type (Arroyo *et al.*, 2015). **Figure 10** illustrates the concept of the minimum and maximum green times.

Gap time (Unit Extension)

Gap time, or unit extension, is a maximum time of headway that cuts the green interval continuation before reaching the maximum green. Sometimes called passage time or unit extension, gap time indicates if traffic is operating efficiently or not. Longer gap time leads to less efficiency of the intersection. The controller keeps extending the green time as long as the headway does not exceed the assigned gap time, which is usually between 2s to 3s. The sensitive point is that gap time has a direct influence on the efficiency of the signalised intersection. **Figure 11** shows how gap time works to cut the green before reaching maximum green time. The relationship between gap time and the flow rate is shown in **Figure 12**.

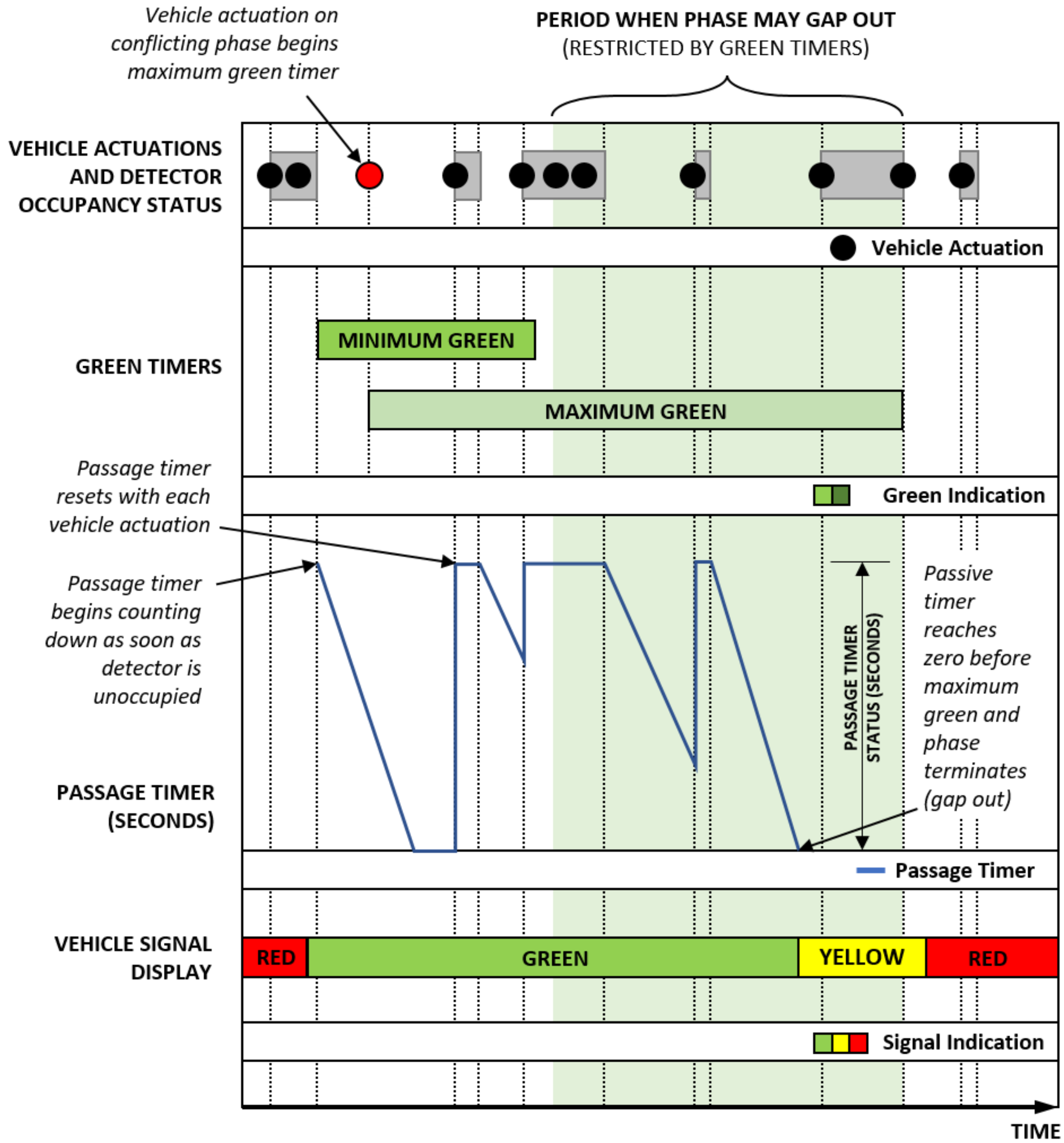


Figure 11: Gap time (Arroyo *et al.*, 2015)

Table 1: Basic Signal Timing Parameter Guidance (Arroyo *et al.*, 2015)

Timing Parameter	Consequence for Too Little Time	Consequence for Too Much Time	Dependent on Variables Including
Yellow Change	• May create a dilemma zone (Type I) • May cause a higher frequency of red-light running	• May encourage disrespect by familiar drivers	• Driver perception-reaction time • Vehicle deceleration rate • Vehicle approach speed • Approach grade
Red Clearance	• Potential conflict after phase begins	• Wasted time at the intersection	• Intersection width • Vehicle length

			• Vehicle approach speed
Minimum Green	• May violate driver expectations (leading to a possible increase in rear-end crashes) • May not accommodate pedestrian needs • May not accommodate bicycle needs	• Wasted time at the intersection	• Driver expectancy • Detector locations • Number of queued vehicles • Pedestrian intervals • Bicycle speed and acceleration
Maximum Green	• Some vehicles may not be served because the phase capacity is inadequate for demand	• Wasted time at the intersection (mainly if there is broken detection) • Possible queuing on movements with long delays	• Vehicle demand • Intersection capacity
Passage Time (Unit Extension or Gap Time)	• Green may end prematurely before all vehicles have been served	• Delays to other movements caused by extension of the phase	• Detection design • Detection mode • Vehicle approach speed
Walk	• May not accommodate high volumes of pedestrians	• Wasted time at the intersection	• Pedestrian volumes • Push button locations • Pedestrian crossing distance • Pedestrian walking speed
Flashing Don't Walk (FDW)	• May not accommodate the time needed for pedestrians to cross the street	• Wasted time at the intersection	• Pedestrian crossing distance • Pedestrian walking speed

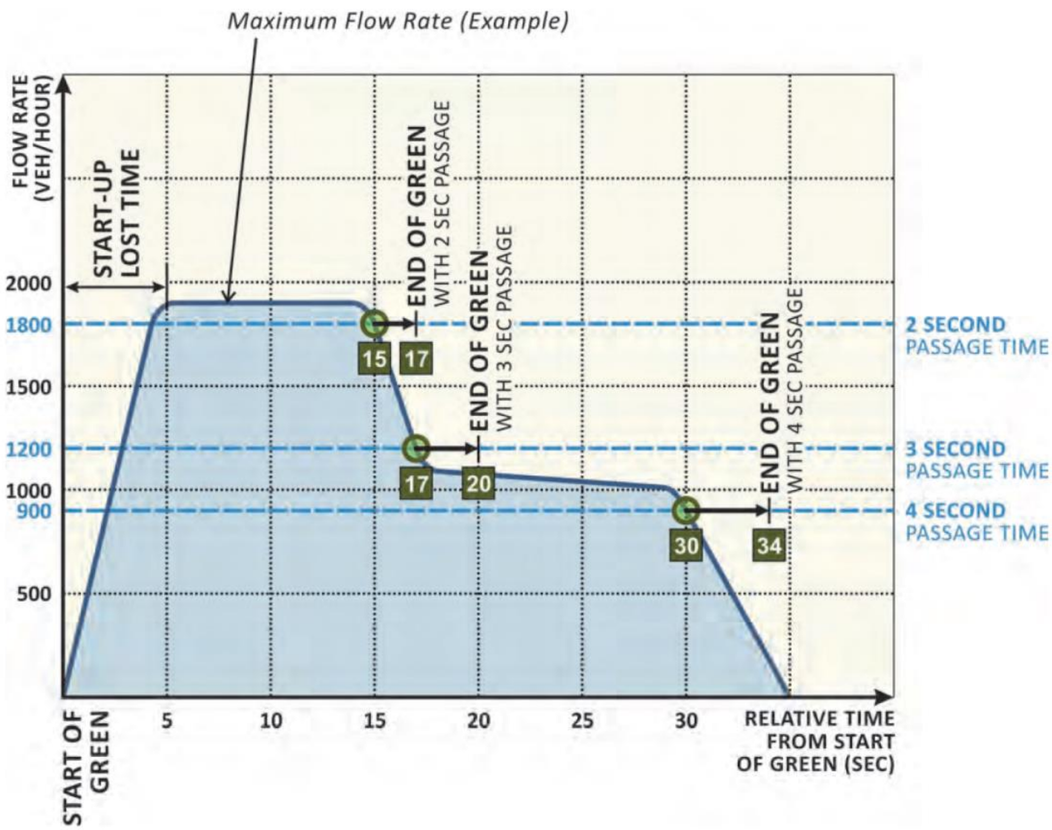


Figure 12: Gap time and flow rate relationship (Arroyo *et al.*, 2015)

2.2. Traffic signal operational objectives and performance measures

Performance measures and operational objectives are one of the most crucial steps in an outcome-based process such as traffic signalisation (Arroyo *et al.*, 2015). Here, user priorities are defined by objectives and their performance measures. When determining signal timing values for a specific location, outcome-based processes are preferred over software-based solutions. Road users should easily understand several aspects of performance measures such as a number of stops or travel time. Whereas aspects such as delays might support the system operator rather than road users. **Table 1** shows basic signal timing parameter guidance.

2.2.1. Selection of the operational objectives

The practitioner will have a bright idea regarding the timing values that represent user needs only through establishing a set of objectives. They might be chosen by reading through previous problems or by conducting a comprehensive assessment within a study area. After defining operational objectives, practitioners can easily illustrate the deficiencies within the system. Possible operational objectives mentioned in (Arroyo *et al.*, 2015) based on the road and system users include:

- **Safety:** the main purpose is to minimise collisions between vehicles, pedestrians, bicycles, and public transit and provide sufficient times for movement execution.
- **Mobility:** distributing the capacity across movements in a way to reach the most efficient case; prioritising should be made based on time movements need without delaying other movements, and pedestrian and bicycles movements, as well as vehicle movements, should be served efficiently.
- **Environmental impact mitigation:** pollution should be minimised by reducing vehicle delay, idling, and a number of stops.
- **Queue length management:** critical lane groups should be free of excessive traffic queues.
- **Vehicle and driver costs:** vehicle operating costs and driver delay costs should be reduced by reducing vehicle delays and a number of stops.
- **Accessibility:** all pedestrian including special needs groups should have time to execute their movements; transit vehicles should be allowed to execute manoeuvres, and transit passengers including the special needs groups should have time to access transit.

2.2.2. Performance measures

Measures for evaluating the success of timing plan performance should be established for each operational objective. A practitioner usually uses delay and stop strategies as measures because of their apparent easy calculation. However, the optimisation software might fail to provide the perfect calculation for performance measures designed for each operational objective. Data collection from the study area can provide the correct performance measures, but not always practice (Arroyo *et al.*, 2015).

a) Quality of progression

According to the Manual of Uniform Traffic Control Devices, the quality of progression can be calculated in two ways (MUTCD, 2009). First by calculating per cent arrival on the green, which measures the number of users arriving during a green interval to an intersection, compared to users who arrive during a red interval. Time-space diagrams are used through optimisation software to gauge the effectiveness of progression within an intersection (Arroyo et al., 2015). Second by calculating the ratio of arrival in the green interval to arrival in the red interval, which measures the quality of progression among different corridors. In this second calculation, the proportion of users arriving at an intersection on green and red is calculated and can be used effectively to measure the progression quality by corridor level.

b) Number of stops/km

The number of stops per kilometre might be a better performance measure compared with the previous one. Three critical elements of this performance measures are phase status, queue profile, and a number of users arriving at an intersection (Arroyo *et al.*, 2015). Furthermore, the number of stops should be reduced if the practitioner desires to have reduced emissions from vehicles and improved air quality.

c) Travel time/Average speed

Travel time can easily measure the overall traffic movement quality within an arterial. This performance measure is easily understood by all the stakeholders, yet despite being one of the most easily understood performance measures, travel time does not represent how the traveller experience is impacted by stops and short delays. Hence, this performance measure should not be used while excluding stops and delays. Modern practitioners can estimate the arrival on green and also the approach delay, thus using the overall travel time as an aggregate measure of performance (Arroyo *et al.*, 2015).

d) Delay

Delay is the time difference between a free-flowing uninterrupted travel experience and the current situation of a user. Practitioners have included delay as one of the primary measures in optimisation models primarily due to its easy quantification (Arroyo *et al.*, 2015). Furthermore, a user's operating costs can be measured with the help of this performance measure. At a signalised intersection, the delay can result from long queues at the intersections impeding travel, signal controlling procedures, distracted drivers, bus blockages, etc.

A practitioner must understand those delays and exactly how they impact the user experience to formulate an optimisation model. Furthermore, delays can be expressed in two ways, unit delay (s/Veh) and total accumulated delay (Veh/hr) (Arroyo *et al.*, 2015).

e) Queuing

The number of vehicles and users waiting for the green interval at the intersection is referred to as queue or queue length. Usually, the queue is measured at the beginning of the green interval when the vehicle count is at its highest. Factors such as signal timing, detection parameters, and downstream and upstream traffic might influence the queue length (Arroyo *et al.*, 2015). Queuing can be measured by both optimisation software and onsite study.

f) Intersection safety

Several common safety-related performance measures are influenced by signal timing such as number and type of accidents, the frequency of users violating the red signal, and a number of potential conflict points related to vehicles, pedestrians, or bicycles. The types of collisions at an intersection, such as head-on, angle, sideswipe, or rear-end collisions, also offer safety-related performance measures (Arroyo *et al.*, 2015).

2.3. Countdown timers

Researchers have developed several systems over the years geared explicitly toward vehicle drivers that inform them of signal phase transitions. These systems are used to gauge the overall safety level and driver's opinion of the system and signal phase transitions. Overall, these systems are of three categories:

- Signal light sequence
- Signal countdown timers
- Advanced warning flashers

These warning systems might have both positive and negative impacts on safety, as revealed by numerous previous studies. However, in this report, only the SCT will be examined.

2.3.1. Background

In most traffic-congested Asian cities, SCTs are efficiently used as means of advanced traffic information systems. These devices went through a somewhat arduous journey of evolution starting with distance-referencing aids in earlier days to the clock-like dial; and from flashing green to flashing amber (Mahalel, Zaidel and Klein, 1986; Mussa *et al.*, 1996).

A digital clock is placed beside the signal head, visible to vehicle drivers and pedestrians, and shows the time remaining for each phase of signal transition (see **Figure 13**). Vehicle drivers can better understand the amount of time remaining for an upcoming phase, and hence they are endowed with better decision-making capabilities. Also, these countdown timer devices offer substantial benefits to both controller and vehicle drivers. The purpose is that there will be fewer collisions among vehicles and pedestrians, better traffic flow, and reduction of stress for vehicle drivers and pedestrians while in the queue and waiting for a signal to turn green.

One huge benefit that these devices might provide is that there will be a smooth queue discharge in most cases. Drivers are alerted in advance of an upcoming signal change, and they can prepare accordingly. However, the number of studies claiming this benefit are preferably few, and researchers show a mixed reaction when asked about this issue. However, despite being implemented in many other countries, SCT devices are still unapproved in the United States. Hence, transportation professionals are often unaware of the level of impacts these timer devices could have in managing traffic flow and reducing crashes.

Figure 13: PCT at a signalised intersection in Abu Dhabi

Countdown timer devices are intended for a smooth transition of vehicles or other travellers across an intersection. Many traditional signalling systems fail to reduce lost time, although appropriate management of traffic flow and are ultimately rewarded with capacity reductions in those intersections. Traditionally, drivers are expected to react to signal phase transitions, such as when the light turns from green to red or vice-versa. However, in most cases these changes are unpredictable and come as a surprise for most drivers, making them confused on whether to stop or proceed. As a result, traffic congestion and collisions take place. However, these disadvantages could be minimised by installing another device besides the signal head, that would warn drivers, in advance, regarding a change in signal phase transition. While the use of these devices is frequent in East Asian countries, for the United States use is negligible.

SCT devices provide vehicle drivers with information regarding a status change in signal transition. As a result, they might make informed choices on when to enter the intersection, and when not to. These devices are an auxiliary part of the whole system and are therefore designed to be used in conjunction with the traditional and more widely used signal indication systems.

According to (Keegan and O'Mahony, 2003), a PCT is a device designed specifically to show the remaining time of each red or green phase to pedestrians crossing the intersection. PCTs are designed primarily for pedestrians who find it hard to cross the intersection within the stipulated time frame. This device was implemented in several USA cities, and the results have been astounding. Their colossal success prompted authorities to consider installing these devices at all pedestrian crossings throughout the USA.

PCTs are a byproduct of the interaction between intelligent transportation systems and traditional traffic signals, and they might shape pedestrian behaviour and ensure safety. Pedestrians have information on time remaining, usually in seconds, for them to cross the road, or the time remaining until they can start moving. As evidenced by past studies, pedestrians are endowed with better decision-making capabilities ensuring overall safety and traffic flow. However, the use of these countdown timers can be debated because, despite their apparent benefits such as easy installation and better management of traffic flow, there are certain downfalls. For example, slow pedestrians might accumulate on one side of the road, pedestrians might fail to cross the road before time runs out, and these devices are of little use to visually impaired pedestrians (Martin, 2006).

Furthermore, previous studies undertaken to observe pedestrian behaviour at signalised crossings revealed some glaring flaws within the whole idea. Researchers found a high percentage of people crossing the street at the end of Flashing Do not Walk (FDW) signs, which is dangerous, to say the least. Also, researchers pointed out that pedestrians, compared to a regular intersection scenario, are eight times more likely to collide with moving vehicles while rushing to cross the street at the end of the Steady Do not Walk (SDW) signals ((King, Soole and Ghafourian, 2009). These findings have necessitated a large-scale study on the efficacy of these countdown timer devices, and their impacts on overall traffic safety.

2.3.2. Design purpose of system countdown devices

The countdown devices are designed to help improve overall safety conditions and maximise operational benefits through:

- Reducing delay through building up capacity at signalised transitions
- Helping drivers with a better understanding of traffic flow at the intersections
- Reducing incidents of crashes among vehicles, bicycles, and pedestrians
- Helping drivers make informed choices based on the remaining time left on each green or red phase

In western countries, devices used at the intersections usually use actuated time plans, as they give off a better idea regarding traffic flow and a number of vehicles within the queue. Hence, the time for each green or red phase changes per cycle, but drivers find it difficult to gauge the time remaining for each phase of red or green. On the other hand, some Asian cities use fixed time plans and, no matter what the traffic volume is, there will be a fixed time allocated for each green and red phase. Studies revealed several benefits of installing countdown timer devices at the intersection including less environmental pollution, reduced travel time, and a drastic reduction in the number of crashes which will be discussed in detail in literature review chapter

3. Literature review

SCTs can mainly be divided into two categories based on the user type. A vehicle countdown timer is used by drivers, and a pedestrian countdown timer is used by pedestrians. The efficiency of signal countdown timers (SCT) in general has been analysed by many researchers studying various factors. In this chapter, VCTs and PCTs have been evaluated based on different factors.

3.1. Vehicle countdown timer

Based on many studies in multiple cities around the world, VCTs show an effect on aspects such as drivers' perception-reaction time, start-up lost time, safety and red-light violations, dilemma zones, queue discharge, etc. Some studies found a positive effect, whereas others found an opposite effect. Also, some studies showed no effect for the VCT on some of those aspects. The effect of VCT can be evaluated based on the running interval. For example, saturation flow rate, headway, start-up lost time, and queue discharge can be evaluated during the green interval. Red-light violation and safety aspects or frustration relief can be evaluated during the red time interval. Dilemma zone and driver behaviour are evaluated in the yellow time interval.

3.1.1. Effect of VCT during the red time interval

Safety could be the essential element of the VCT aside from the efficiency of the intersection. Most of the researchers investigated either partially or entirely on the safety of VCTs. One of the significant safety concerns at signalised junctions is the phenomenon known as red-light running or violation. Apart from an adequate amber period given after the end of the green and before the commencement of red, it is also quite usual to have adequate all-red phase to further enhance the level of safety at the junction just in case a vehicle is not able to stop in time before the end of amber.

It has been suggested that the VCT may assist drivers to stop before the commencement of red as the driver would know the amount of green time available before it changes to amber and then red. This would help eliminate the red-light violation phenomenon and hence increase the level of safety at the signalised junctions. To investigate this claim, a study has been conducted with mixed results. While some reports showed positive impacts of VCTs, others showed the opposite. In Bangkok, where VCTs have been installed since 2002, in less than five years more than 400 intersections were equipped with VCTs, according to (Limanond, Prabjabok and Tippayawong, 2010) who conducted a study on an intersection with and without a VCT. They found that red-light violations under the ‘‘with timer’’ condition occurred 35 times, half of the number of red-light violations under the ‘‘without timer’’ case (70 times). Furthermore, they found a reduction in the maximum violation time when the countdown timer was used.

Under the ‘‘without timer’’ condition, the maximum violation time was 4.13s after the onset of the red phase, while it reduced to 3.08s under the ‘‘with timer’’ condition. These two impacts of the timer would help in creating a safer environment for driving and reduce the likelihood of right-angle collisions at the intersection. This might be the reason why the drivers mostly favoured having a VCT at the junctions. In the same study, the authors conducted an opinion survey where they found that the majority of local commuters are favourable toward the countdown timers. More than 95% of the car drivers interviewed recognised that the countdown timers were beneficial to them, and almost all of them would encourage the Bangkok Metropolitan Administration to install more countdown timers on the street network.

As per (Limanond, Prabjabok and Tippayawong, 2010), the countdown timers were installed at the intersections in early 2006 but the researchers still found the reduction in red-light violations in the middle of 2007, which is approximately one year after installation of the devices. Thus, the impact of reducing the number of red-light violations seemed sustained over at least 12 months. This contradicts the studies by (Lum and Harun, 2006; Chiou and Chang, 2010), which found that the countdown timers reduced efficiently red-light violation incidents only over the short term. In China, (Ma, Liu and Yang, 2010) and (Huang *et al.*, 2014) also found a reduction in red-light violations after installation of VCTs by assisting the driver’s behaviour during the amber time. In Malaysia, (Kidwai, Karim and Ibrahim, 2005) analysed seven signalised intersections in non-CBD areas, four with countdown timers and three without timers, for red-light violations. The results showed a reduction in red-light violations from an average of 66.2% to 37.1%. Nevertheless, there was still a relatively high occurrence of red-light violations at the countdown signalised junctions. They attribute this high number of red-light violations to the inadequacy of amber time which does not match with the ability for a vehicle to stop safely while moving at particular approach speed. Another study in the same country and by the same researchers contradicts findings (Ibrahim, Karim and Kidwai, 2008) and found that the rate of violation increased from 24% to 30% in cases with VCTs which was similar to findings of (Liu *et al.*, 2012).

According to (Li *et al.*, 2014), drivers become ready to depart faster by 32% with VCT, apparently because of reduced perception-reaction time. The authors found a reduction in perception-reaction time from 2.12s to 1.48s leading to reduced start-up lost time. In (Limanond, Prabjabok and Tippayawong, 2010) and (Sharma, Vanajakshi and Rao, 2009) studies, there was a positive impact of VCT implementation. (Limanond, Prabjabok and Tippayawong, 2010) found a significant decrease in lost time by 22%. 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 the countdown timers are not used. In fact, this favourable effect of countdown timers has been perceived by most of the general public according to (Limanond, Prabjabok and Tippayawong, 2010). They found that 69.4% of motorcycle drivers and 63.2% of car drivers agreed that the timing information given by the countdown timers assisted them in preparing to proceed through the intersection when the green phase began. There were similar findings in a study by (He *et al.*, 2009).

The majority of both car driver and motorcycle driver groups agreed that countdown timers would help in relieving their frustration from stopping for long and uncertain amounts of time during the red phase (64.4% and 51.8% respectively). Also, they agreed that it could help in assisting them to promptly proceed through the intersection when the signal turns green (63.2% and 69.4%, respectively) (Limanond, Prabjabok and Tippayawong, 2010). Less than half of the respondents utilise information from the timers for better usage of waiting time spent during the red phase, or for switching off the car engine while waiting in the standing queue. (He *et al.*, 2009) found that 86.0% of the drivers believed that intersections with signal countdown devices were safer and 26.5% believed that their waiting time at intersections having signal countdown devices was shorter than at intersections having regular traffic signals.

3.1.2. Effect of VCT during the yellow time interval

Drivers approaching a signalised intersection during the amber time need to decide whether to enter and clear the intersection or to make a stop. This decision-making process can be significantly affected by a critical part of the signalised intersection called the dilemma zone, within which an individual driver can neither safely clear the intersection nor make a stop. In response to the needs of improving traffic safety, transportation professionals have developed many methods to reduce the complexity of driver's decision-making during this critical phase-transition period. As one of the aids to drivers, VCT allows drivers to have advance information to envision the imminent termination of the green phase and thus make proper decisions.

When assessing the effect of a VCT during the amber time interval, (Ma, Liu and Yang, 2010) found various positive points. They found that installation of VCTs may encourage drivers to pass the stop line during the amber time with higher speeds and thus result in better utilisation of the amber time and increased capacity of the intersection approach. However, the higher speed may increase the probability of accidents. The survey results by (He *et al.*, 2009) showed that 42.5% of the drivers believed that VCTs tend to cause speeding across intersections. This explains the findings of (Liu *et al.*, 2012) and (Long, Liu and Han, 2013), who found that the percentage of stopping vehicles after yellow onset dropped from 39.1% to 19.6%, while the percentage of crossing drivers increased from 60.9% to 80.4%. At the same time, the likelihood of running the red light increased from 7.2% to 13.5% which was similar to findings by (Ibrahim, Karim and Kidwai, 2008). (Ma, Liu and Yang, 2010) found also that the installation of VCTs was able to smooth the driver's response to the phase transition and efficiently prevent sudden changes of speeds and eliminate the intersection dilemma zones by allowing drivers to envision the phase transition and make decisions in advance, which is similar to findings in (Long, Liu and Han, 2013) but in contrast with (Chiou and Chang, 2010) who imply that the provision of VCTs causes significant deviations in driver decisions to stop. Of the drivers surveyed by (He *et al.*, 2009), 75% believed that the existence of the VCTs could help them to avoid using the emergency brake when green traffic signals turn yellow. Those changes in driver behaviour patterns can be used to shorten the amber time without incurring a dilemma zone problem so that the total lost time in the cycle length is reduced and the overall capacity of the intersection is improved (Ma, Liu and Yang, 2010). Another study which compared VCTs with other time reminder strategies, such as green flashing or common signal devices, found VCTs to have the most significant effect in reducing the possibility of being trapped in dilemma zones than other strategies did (Huang *et al.*, 2014). (Limanond, Prabjabok and Tippayawong, 2010), stated that the countdown timers had no or little impact on traffic characteristics during the amber phase.

Many car drivers and motorcycle driver groups agreed that the timers would assist them in making a better judgment about stopping during the phase change to red: 54.4% and 47.1%, respectively (Limanond, Prabjabok and Tippayawong, 2010).

3.1.3. Effect of VCT during the green time interval

During the green time interval the saturation flow rate, saturated headway, headway gap, and start-up lost time are the most frequently assessed elements. (Limanond, Prabjabok and Tippayawong, 2010) found that average saturation headway in the VCT condition was more significant than saturation headway without VCTs. Although it was not significantly different, one reasonable explanation is that, while the queue is proceeding through an intersection without VCT during the green interval, drivers are uninformed of the exact termination of the green time, and so are likely to follow the preceding vehicle more closely to improve their chance of proceeding through the intersection before the green phase ends. With the presence of the countdown timers, however, drivers know the exact remaining time before the green phase ends, and can follow the preceding vehicle at a more comfortable distance to proceed through the intersection with larger headways. The larger saturation headway in the study led to a decrease in the saturation flow rate with VCTs which was similar to findings by (Kidwai, Karim and Ibrahim, 2005). With the same researchers in a different study (Ibrahim, Karim and Kidwai, 2008), an opposite finding resulted which was similar to findings by (Wenbo *et al.*, 2013). A detailed study about saturation headway by (Sharma, Vanajakshi and Rao, 2009) in Chennai, India, presented insights gained on queue discharge characteristics at signalised intersections under heterogeneous traffic conditions. They found that the saturation headway did not follow a similar trend during the green interval. At the beginning of the green interval, there was a little saturation headway as well as toward the end of green time, mainly due to vehicles rushing as the end of green approached.

The majority of both car driver and motorcycle driver groups agreed that countdown timers would help in ensuring confidence in driving through the intersection during the green phase: 62.8% and 54.1%, respectively (Limanond, Prabjabok and Tippayawong, 2010).

3.2. Pedestrian countdown timer

It is stated in (Zegeer, Opiela and Cynecki, 1985) that the primary concern and focus of the pedestrian is to understand the real meaning of signal indications, where misunderstanding and improper interpretation of indications can lead to accidents and confusion among pedestrians. Sometimes pedestrians are facing lack of time and prefer to return or even stop walking right in the crosswalk after the indication or signal changes. This phenomenon may occur due to not being aware of the remaining time left to cross the road. This move may be dangerous and lead them to make wrong decisions when the speed and remaining time are not synchronised. Therefore, a pedestrian walking speed and time for crossing must be matched accordingly to avoid mishaps.

According to (Tidwell E and Doyle P, 1995), only 50% of pedestrians understand the meaning of Flashing Do not Walk indicators. However, some other researchers have declared that number to be less than 50%. Pedestrians not having sound knowledge regarding FDW signals can lead to risky behaviour and accidents (Singer and Lerner, 2005).

One of the efficient ways to tackle these problems is to install PCTs to facilitate the pedestrian's understanding. PCTs, help to keep the pedestrians updated about the time left to cross intersections, and make up the deficiency in understanding FDW signals (Eccles, Tao and Mangum, 2004). An analysis was done by the Florida Department of Transportation (FDOT) to show the real difference between the understanding of existing conventional pedestrian signals and the PCT. It can easily be observed from the research that pedestrians always found it easier to understand PCTs rather than existing conventional pedestrian signals. PCTs helped pedestrians to make more intelligent moves by adequately showing when to cross, start, and stop or when to wait for the green signal for the pedestrians.

It is also suggested, in research conducted in Korea by (Kim, Kim and Seo, 2002), that PCTs help pedestrians to stop crossing in FDW phase intelligently. This is done by providing information regarding remaining time to cross on display. It is stated that countdown signals may reduce the confusion among pedestrians and make them able to make smart decisions when crossing a road (Pulugurtha, Desai and Pulugurtha, 2010). According to conducted research, there are several advantages to implementing PCTs which may include better comprehension and security of the overall traffic architecture. PCTs may also improve the intersection efficiency regarding secure and sensible attitudes of pedestrians. However, along with all the mentioned advantages, there may also be a disadvantage of PCT which can create a long waiting duration for crossing the road, thus increasing pedestrian stress. The most critical factor of PCTs is to ensure the working efficiency of countdown signals for the safety of pedestrians. Many studies have mentioned different safety features of the PCT (Keegan and O'Mahony, 2003; Harré and Wrapson, 2004; Egan, Hyland

and Planner, 2008; Rafael Aldrete-Sanchez, Jeff Shelton, 2010).

In contradiction, some other authors disagree with benefits and provide some valid points against using PCTs (Cleaver *et al.*, 2011; Vujanić *et al.*, 2014). However, many factors can change a study's results and development, such as environments and structural issues such as allotted phase time and the type of intersection. Several other factors may also be the reason for degraded PCT performance. These factors may include allocated phase time duration and the type of intersection considered. Moreover, pedestrians consider the buffer time between the SDW display and traffic start and may cross during the FDW phase. One cannot declare the whole system unsafe for pedestrians.

Performance and efficiency of PCTs regarding many factors have been analysed and observed by several authors and researchers. Different authors have discussed different performance parameters and factors in their research.

3.2.1. Change in pedestrian behaviour

Many studies have been analysed regarding the change in pedestrian habits after implementation of countdown signs, usually showing positive outcomes (Keegan and O'Mahony, 2003; Eccles, Tao and Mangum, 2004; Harré and Wrapson, 2004; Leistner, 2005; Kennedy and Sexton, 2010; Lambrianidou, Basbas and Politis, 2013; Lipovac *et al.*, 2013). On the other hand, other studies suggested the changes are not significant and pointed to the need for further evaluation (Huang and Zegeer, 2000; Markowitz *et al.*, 2006; Vivek *et al.*, 2008; Arhin, Noel and Lakew, 2011). This inconsistency in results may be attributed to the fact that PCTs can have a positive or negative change in the behaviour of pedestrians based on their local environment, as they help pedestrians to organise themselves and form well-thought decisions.

Another study, performed in New Zealand, asserts that pedestrians' behaviour is different depending on where the study is located, which could also alter the results having a positive or negative influence on decision-making (Hooper, Vencatachellum and Tse, 2007).

The changes in pedestrian behaviour can occur in different types of crossing based on the speed and time of crossing. Violators, for example, are pedestrians who cross during the SDW or FDW interval. In some studies, a proportional and vital decrease in violations was observed (Keegan and O'Mahony, 2003; Eccles, Tao and Mangum, 2004; Leistner, 2005; Wanty and Wilkie, 2010; Lipovac *et al.*, 2013; Xiong *et al.*, 2014). In contrast, other researchers concluded an adverse outcome of increasing violators (Huang and Zegeer, 2000). This result must be carefully analysed since the "control" and "treatment" sites were not the same, which could compromise the data in question. Furthermore, it must be taken into consideration that non-compliance does not necessarily mean a higher risk for pedestrians, as long as they adjust themselves by increasing walking speed (Huang and Zegeer, 2000; Leistner, 2005; Cleaver *et al.*, 2011).

Another pedestrian behaviour is called “late starters” which refers to those pedestrians who begin to cross at the FDW interval. (Wanty and Wilkie, 2010) found a statistically significant increase (20% to 23%) in the number of late starters with PCTs. Also, a study by (Cleaver *et al.*, 2011) found an 11.9% increase in late starters that was offset by an 11.3% reduction in pedestrians who began to cross during the SDW signal. However, this undesirable effect was nullified as it was found that there was a 12.3% increase in successful crossings by the late starters. Again, as mentioned previously, an increase in the number of late starters does not necessarily imply reduced safety as in addition to the buffer time, pedestrians tend to adjust speed according to the time displayed to finish crossing in time. However, this is not the case for slow or elderly pedestrians or pedestrians who happen to misinterpret the time needed to cross.

In contrast to late starters, “late finishers” are those pedestrians who happen to run out of time or remain in the crosswalk once the SDW is displayed. This parameter is essential to evaluate safety in general, but also concerning extremes of age pedestrians, children, and slow walkers. The results obtained in several studies were positive regarding safety and found that the proportion of pedestrians that remained in the roadway when the SDW showed decreased significantly (Leistner, 2005; Markowitz *et al.*, 2006; Xiong *et al.*, 2014).

Although having good results in these studies, there was a statistically significant increase (about 6%) of late finishers found in studies conducted in New Zealand (Wanty and Wilkie, 2010) and in Korea (Kim *et al.*, 2009). This can again be a result of misinterpretation of time required to cross or not to understand the sign, which leads pedestrians to decide to cross with less time available and fail to finish in time.

Although PCTs have some positive influence on crossing habits, an undesirable consequence is an increase in the proportion of late starters. In logical thinking, it would be expected to increase in the percentage of late finishers in the study, which did not happen. The conclusion, therefore, is that pedestrians have made efforts to adjust their speed and cross before nearing the end of the green time (Huang and Zegeer, 2000; Eccles, Tao and Mangum, 2004; Supernak, Verma and Supernak, 2013). This implies a progressive effect on safety. Other studies also came to the same conclusion. (York *et al.*, 2011) Observed this result in London, and another study by (Schmitz, 2011) found similar findings in the USA, where average speeds increased by 2ft/s. An interesting point has been addressed, showing that despite the reduced number of slow adult pedestrians, these results did not apply to children (Lipovac *et al.*, 2013). This idea restates the thought that slow walkers are mainly composed of extremes of age.

On the other hand, other studies showed that many factors could influence either positively or negatively on pedestrian’s behaviour, such as the traffic volume, type of intersection, and time comfort levels—aspects that may confer a false sense of protection and lead to unsafe choices. (Martin, 2006) Observed an increase in the number of pedestrians who crossed the road during the SDW signal. In another study by (Lipovac *et al.*, 2013) the authors described a statistically significant difference in slow pedestrians when categorising them by gender/age (decrease in male, children, and increase in female).

“Runners” is a term that refers to those who run to finish crossing, and the term “aborters” is used to identify those pedestrians who initiate crossing but go back to the curb. In San Francisco, the countdown signals gave a positive outcome by decreasing the number of runners (Markowitz *et al.*, 2006). This shows the importance of understanding the meaning of countdown signals to make better decisions (Huang and Zegeer, 2000). Similarly, a significant decrease was shown in New Zealand (7% to 5%). This shows the positive influence of countdown signals and the capacity to influence better decision-making.

The gender of pedestrians can also have a significant influence on behaviour when regarding safety measures. Men represent a more significant portion of violators, while women tend to adopt a safer pattern (Huang and Zegeer, 2000; Tom and Grani, 2011; Lambrianidou, Basbas and Politis, 2013; Lipovac *et al.*, 2013; Vujanić *et al.*, 2014; Wanjing, Liao and Bai, 2015). According to (Tom and Grani, 2011), women are more likely to make safer decisions, and men are more susceptible to take risks and to be unmindful of cars.

The behaviour tendencies also differ regarding the average age of pedestrians, with younger people taking more significant risks (Huang and Zegeer, 2000; Moyano Díaz, 2002; Lambrianidou, Basbas and Politis, 2013; Lipovac *et al.*, 2013; Richmond *et al.*, 2014; Vujanić *et al.*, 2014). (Huang and Zegeer, 2000) Suggested that there is a difference in geographical areas that have countdown signals at intersections, especially in prevailing locations which have a senior citizen population, since the information of time available for crossing makes it easier for slow pedestrians not to miscalculate the necessary time to cross. The results, when compared, show that seniors have better compliance with the signals (Wanjing, Liao and Bai, 2015), an idea that can be explained by the illusion of strength and invincibility present in adolescence creating a tendency for younger people to take higher risks.

Despite efforts to improve signal use and countdown systems, the elderly population seems to feel uncomfortable when passing an intersection. Although older populations are seen to comply more, younger pedestrians are observed to feel more comfortable in contrast to older pedestrians when passing particular junctions (Lambrianidou, Basbas and Politis, 2013).

3.2.2. Pedestrian-vehicle conflicts

Several studies point out a link between the presence of PCTs and an increased number of pedestrian-vehicle conflicts. Despite the excellent intention present on the use of signs, they may undesirably cause an increase in collisions with crossing vehicles and right-turning vehicles. These situations occur when a pedestrian tends to walk faster when the FDW phase is almost at its end (Wanjing, Liao and Bai, 2015).

Contributing to this outcome, quantitative data has been collected by (Richmond *et al.*, 2014) in which they found a 24% rise in the number of accidents. Several possibilities for these occurrences can be hypothesised: an attempt to save time by pedestrians or vehicles, or the misinterpretation of the signs, a point that has been presented since the beginning of this paper. Other than that, (York *et al.*, 2011) indicate that traffic volume also influences the number of accidents, more frequently happening in medium and low vehicle traffic, since pedestrians adopt more impulsive behaviour.

On the other hand, several studies link the adoption of countdown signals as a factor to decrease pedestrian crashes, some presenting much lower numbers of accidents than before. A study in San Francisco showed the installation resulted in a 52% decrease in pedestrian crashes, although the data has a small number of conflicts to be considered (Markowitz *et al.*, 2006). Similar results were found in Michigan and elsewhere, with an even higher decrease (Eccles, Tao and Mangum, 2004; Leistner, 2005; Pulugurtha, Desai and Pulugurtha, 2010; Pešić *et al.*, 2012; Huitema, Van Houten and Manal, 2014; Zhou, Roshandeh and Zhang, 2014). Furthermore, there was a study that presented no crashes at all, but the period evaluation, in that case, ran for only three months (Singer and Lerner, 2005)

3.2.3. Other factors

As all these points explain, it is possible to understand that behaviour can be altered due to a combination of several factors, such as traffic volume, age and sex, composition of the population in the location studied, length of crossing; in contrast with the simple idea that installing a countdown sign would be a unique factor (Lipovac *et al.*, 2013; Koh, Wong and Chandrasekar, 2014). Furthermore, other studies in Asia observed yet different influences such as some traffic lanes, pedestrian culture, type of carriageway, and more (Guo *et al.*, 2011).

The influence of FDW signs in forcing pedestrians to wait seems to be useful in longer crossings, in contrast to shorter crossings where the signs seem not to affect. Once again, locations with higher volume seem to have a lower compliance rate (Pulugurtha, Desai and Pulugurtha, 2010; York *et al.*, 2011; Lipovac *et al.*, 2013; Supernak, Verma and Supernak, 2013). Similarly, (Koh, Wong and Chandrasekar, 2014) observed that the probability of pedestrians committing violations is attached to the idea of the time-gap between cars in the street (Lipovac *et al.*, 2013).

Surprisingly, even the design of the signals seems to affect decision-making. It is possible to notice an increase in violations by research done in Serbia, where the green phase was only 10s (Vujanić *et al.*, 2014). (York *et al.*, 2011) found a 6% increase in violations when changes in signal timings were considered. (Guo *et al.*, 2011) point out the more significant chance of violation when waiting time is longer than 40s, with the possibility of leading to a higher number of violations.

Group influence was also observed in interesting studies carried out (Keegan and O'Mahony, 2003; Rosenbloom, 2009) to understand the effect of social values in safer decision-making, proving that when regarding more than their safety, people tend to be more careful. However, (Ren *et al.*, 2011) observed the opposite scenario in a group of pedestrians tending to violate if one person violates.

In conclusion, the evaluation of countdown signals and their efficiency to improve pedestrians' security is a complex matter, which involves several factors that may or not be interlinked. Furthermore, a few effects discussed above need to take into consideration the individual variability and subjective thinking of each (Hooper, Vencatachellum and Tse, 2007).

Finally, professional opinions around the theme are mixed, presenting studies that contrast one another, leaving the matter as a good debating point for further analyses, and also making the installation of countdown signs debatable. It also must be noted that external factors have a significant influence on study results, which could explain the mixed opinions. This idea only emphasises the fact that it is imperative to conduct further research to determinate their efficiency since a further knowledge of the impact of countdown signals will lead to an increase in use in the manner most effective.

3.3. Summary and conclusion

The SCT is a warning device for road users to identify the exact time remaining for the change from the red phase to green or vice versa. This information from the device might have effects on safety, delays, flow, and drivers' and pedestrians' behaviour. The SCT can be divided into two types based on the users. Vehicle countdown timer (VCT) which is used by drivers and pedestrian countdown timer (PCT) which is used by pedestrians.

VCT has many advantages which have been stated by researchers. Installation of VCT can reduce the number of red light violations. The result of reduced red-light violations makes driving safer by bringing down the number of right-angled collisions experienced at the intersections. It can help shape the behaviour of drivers on the road during the amber time. VCT reduced perception-reaction time to enable drivers to depart faster on the junctions which lead to a decrease in lost time. Apart from easy passage through the junction, drivers also agreed that VCTs would lend a hand in relieving frustration from stopping for too long during the red phase. VCTs may inspire drivers to drive faster when passing the stop line during amber time making good use of amber time and increasing the intersection approach capacity but at the same time it reduces the safety which has been stated by some researchers. 75% of drivers surveyed believed that VCTs would help them steer clear of using emergency breaks when the light changes from green to yellow.

PCTs help pedestrians understand flash don't walk (FDW) signals, and the time they must cross intersections. This effective understanding of when to stop, cross or start enables pedestrians to make intelligent moves as far as FDW phase is concerned. Further researches showed that PCTs helped reduce confusion among pedestrians enabling them to make smart decisions when crossing the junctions. PCTs also assist pedestrians to comprehend traffic rules better thereby making the roads secure in the long run. They also enhance the efficiency of intersections by improving the attitudes of pedestrians. PCTs help increase the number of late starters according. Apart from late starters, late finishers can also be greatly helped by PCTs. This is because of PCTs minister to pedestrians of all proportions even children and the aged who need more time to cross the road when the stop don't walk (SDW) displays. PCTs help pedestrians increase their speeds and make the cross before time runs out. They also helped decrease the number of runners significantly.

Beside the mentioned advantages, some studies found a negative impact on safety. Most of the negative impact was during the green interval of VCTs. Based on studies, the green VCT has a slightly positive influence on delay and discharge but a negative influence on safety in many cases. On the other hand, red VCT has a positive influence on safety and start-up time. In the case of PCT, study results show better influences either for red or the green PCTs. Therefore, the SCT can be divided into four main categories based on its effects:

- Green VCT
- Red VCT
- Green PCT
- Red PCT

From the user preferences' side, most surveys showed that the majority of pedestrians and drivers prefer SCT displays. Moreover, they thought that the SCT reduced frustration from waiting in a queue and increased safety. **Table 2** summarizes the outcome of the researches regarding SCTs.

Although there are many advantages of SCT, some cities in Asia uninstalled the devices from the current signal control systems due to specific issues:

- The device is constrained so that it that it can only correctly display the remaining time if fixed-time traffic signals installed at the intersections, which have less efficiency compared to actuated signals.
- Field observations have shown that a VCT decreases safety in some cases (mostly related to green countdown timer), which is by itself enough reason not to install it.

As a conclusion to the literature review chapter, the VCT and PCT have many advantages. Red VCT is recommended to be used and installed. Green VCT is not recommended due to its negative effects on safety.

Table 2: Summary of researches outcomes regarding SCT

Research	Outcome
(Kidwai, Karim and Ibrahim, 2005)	a. Reduction of red light violations from an average of 66.2% to 37.1%. b. High occurrence of red light violations at the countdown signalled junctions. c. Increased rate of violations from 24% to 30%. d. Larger saturation headways and decreased saturation flow in VCTs
(Limanond, Prabjabok and Tippayawong, 2010)	a. Decrease in lost time by 22% b. 69.4% of motorcycle drivers and 63.2% car drivers agree to be assisted by VCTs to proceed through the intersection efficiently when the green phase began.

	c. 64.4% motorcycle drivers and 51.8 car drivers agreed that VCTS reduced their frustration from stopping for long amounts of time when red phase began d. 63.2 % motorcycle riders and 69.4% car drivers agreed that countdown timers helped them proceed through the intersections promptly when the signal turns green e. Little or no impact on traffic characteristics during the amber phase a. Red-light violations under the “red light” timer occurred 35 times while those under the “without timer” occurred 70 times. f. Reduction in the violation time from 4.13 seconds to 3.08seconds when using VCTs
(He et al., 2009)	a. Half of the respondents utilize the VCTs during the red phase or switching off the car engine during the waiting period b. 86% of the drivers believed in enhanced safety while using VCTs c. 26.5% believed in shorter waiting times when using VCTs d. 42.5% of drivers believed that VCTs cause speeding across intersections. e. 75% of the drivers believed VCTS could assist them in using emergency brakes when the green light changes to yellow
(Ma, Liu and Yang, 2010)	a. Better utilization of amber time and improved capacity of the intersection approach. b. Smooth driver response during phase transition and eliminated intersection dilemma zones
(Liu et al., 2012; Long, Liu and Han, 2013)	a. Reduction in the percentage of stopping vehicles after yellow onset from 39.1 to 19.6% b. The likelihood of running the red light reduced from 7.2 % to 13.5%
(Chiou and Chang, 2010)	VCTs cause significant deviations in driver decisions to stop
(Huang *et al.*, 2014)	Reduced possibility of being trapped in the dilemma zone

(Tidwell E and Doyle P, 1995)	50% of pedestrians understand FDW signs
(Kim, Kim and Seo, 2002)	PCTs helped pedestrians stop crossing FDW phase intelligently
(Keegan and O'Mahony, 2003; Eccles, Tao and Mangum, 2004; Harré and Wrapson, 2004; Leistner, 2005; Kennedy and Sexton, 2010; Lambrianidou, Basbas and Politis, 2013; Lipovac *et al.*, 2013)	Positive outcomes in pedestrian behaviour when using PCTs
(Wanty and Wilkie, 2010)	Increase in the number of late starters from 20% to 23% when using PCTS 6% increases in late finishers
(Cleaver *et al.*, 2011)	11.9% decrease in late starters as a result of an 11.3% decrease in pedestrians crossing during the SDW signal
(Wanjing, Liao and Bai, 2015)	Seniors comply to PTCs better than juniors
(Richmond *et al.*, 2014)	24% rise in the number of accidents when using PCTs
(Markowitz *et al.*, 2006)	52% decrease in pedestrian crashes

4. Statistical survey

4.1. Introduction

The user perception survey is one of the primary tools to evaluate the acceptance of any traffic control device before installation. Therefore, a typical step before installing a new system or device is to conduct studies of user preferences or opinions. One generally practice is to perform a survey of the road user's population of interest. This chapter presents the static survey of drivers and pedestrians toward the VCT and PCT.

To assess public perception of SCT use in UAE, two questionnaires were prepared. While the first one was prepared to assess the perception of drivers toward VCT, the second one was used to assess the perception of pedestrians toward PCT. Both types of SCTs are already in use in UAE. VCTs for pre-timed traffic signals are installed in Ajman City (see **Figure 14**), which is an adjacent city to Sharjah; therefore, most drivers in Sharjah are already familiar with the technology. PCTs are installed in some of Abu Dhabi City's traffic signals (see **Figure 15)**. Therefore, most of the Computer Assisted Personal Interviewing (CAPI) questionnaires have been conducted near those PCTs in Abu Dhabi. A total of 1,000 valid questionnaires were collected in May 2015. Out of those, 500 were answered by drivers and the other 500 by pedestrians. About 200 CAPI questionnaires were collected at different places from different cities for the drivers, and 272 CAPI questionnaires were collected directly from pedestrians crossing intersections where a PCT is installed. The remaining 300 questionnaires for the drivers and 228 for the pedestrians were collected online using Computer Assisted Self Interviewing (CASI).

The driver questionnaire included three sections. The first section included demographic and general questions. The second section contained questions related to the red interval countdown. The third section asked questions related to the green timer. For the pedestrian questionnaire, there were two additional general questions about PCTs. The design of the questionnaire was adapted partially from a study performed by (Limanond, Prabjabok and Tippayawong, 2010) which ensures the reliability of the questions used in the survey. Most of the questions were closed questions, except the last comments box was open-ended to give the participants the freedom to write about their opinions. Research questions involved multiple choice responses so participants would invest less time than on open-ended questions which are free. Some survey questions involved responses in the form 'yes or no', Likert scale (strongly agree to strongly disagree scale) or drag-down options.

Figure 14: VCT at a signalised intersection in Ajman

Figure 15: PCT at a signalised intersection in Abu Dhabi

4.2. Statistical analysis of driver's survey

4.2.1. Questionnaire structure and questions

The objective of the driver's statistical survey focused on driver comprehension and preferences toward VCT in the UAE. Survey questions were designed to study four categories:

- Question A to G: Demographic and general questions
- Question 1 – 4: Red countdown timer
- Question 5 – 6: Green countdown timer
- Comments box: Open-ended question

The questionnaire consisted of 13 questions and a comment box in both English and Arabic languages created using Google Forms. Based on a realistic model of the members of the society, a target was set to collect distributed data of drivers representing the society in the UAE.

Demographic and general questions

To collect the demographics of the participants, some general questions were asked. The first question was about the zone or emirate of residence. It was essential to know the resident's emirate because each emirate has slightly different characteristics of traffic control. For example, the countdown timer is available in Ajman and Um Al Quwain only. This might affect the answers from a driver who used to pass through intersections with countdown timers and a driver who never tried to pass through an intersection with a VCT. The second question was about the resident's status. It has been divided into three categories. The first category is "Resident", which means one who is living in UAE as a resident but not Emirati. The Emiratis come under the second category which is called "Local". The last category is "Tourist". The third question was about gender. The fourth question was about the age group, divided into five groups. The age started from 18 years because it is the age of getting a driving license. The first age group was between 18 to 24. Those are generally college students and new drivers. The next age groups were divided every ten years. The fifth question was about educational level, divided into three categories: participants who had a high school degree and below, undergraduate, and postgraduate. The sixth question was whether they had an opinion about the VCT or not. This question was asked because most of the surveys had been conducted in Sharjah where there are no VCTs installed. Moreover, to make sure that the participant understood the questions, a brief description about VCTs was given. The last question was about the daily car trips, to find out the difference between expert and non-expert drivers' answers.

Questions related to the red countdown timer

Questions 1 - 4 focused on red countdown timers as listed below:

1. Relieve frustration from stopping for long and uncertain amounts of time during the red stage.
2. Better use of waiting time spent during the red stage.
3. Turn off the engine while waiting in the queue.
4. Assist in proceeding through the intersection when the signal turns green promptly.

The choice of responses was displayed using a Likert scale from 1 (Strongly agree) to 5 (Strongly disagree) and 6 (Don't know). The first question was whether the VCT relieves frustration from stopping for long and uncertain amounts of time during the red phase. For countries with a massive number of vehicles, large intersections, long cycle times, or long waiting times at intersections, the amount of frustration during the travel time is a phenomenon that everyone tries to eliminate. It was expected that this question would get the most favourable answers and most of the participants could agree to this advantage of the VCT. The second question was if the driver can use the waiting time during the red interval in a better way if they know the remaining time. Both the first and second questions were about the feelings and nerves of the drivers and to judge their mental status toward aggressive driving. The third question was about turning off the engine while waiting. The automatic turning engine off is a feature in new vehicles in many countries in Europe but still not in all vehicles with Gulf Cooperation Council GCC specifications. The question was added to check the acceptability of this feature by drivers in UAE which will affect fuel consumption during long waiting times. The last question was about the preparedness of the drivers before the onset of the green interval. This question is related to perception-reaction times and the start-up lost time.

Green countdown timer questions

Questions 5 - 6 gathered public opinion with emphasis on Green countdown timers at signalised intersections:

5. Assist better judgment to stop when the signal turns red.
6. Ensure confidence in driving thru intersection during the green phase.

From the literature, it was found that the green SCT might have more disadvantages than advantages. Even if that was accurate, checking whether the drivers can feel those disadvantages onsite or not might be useful. The first question was about stopping before the onset of the red interval. This question relates to red-light violations, and whether VCTs can give more information to drivers which helps them to stop at the right time by reducing the dilemma zone. The second question was about the confidence level drivers feel while driving through intersections during the green interval. From the literature, it was noticed that increased confidence during the green interval could reduce the saturation flow rate. At the same time, it can reduce aggressive driving which may lead to traffic accidents or traffic interruptions.

4.2.2. Descriptive statistics

Demographic and general questions

The vast majority of the survey respondents were either UAE nationals (around 32%) or residents (about 66%) as shown in **Table 3**. This distribution is acceptable even though Sharjah demographic statistics in 2015 put UAE nationals to be around 13% of the population. More surveys were purposefully given to Emiratis due to the fact that they drive more frequently and should be very accustomed to local driving behaviour in UAE. Around 89% of the participants were familiar with VCTs. It gives a good indication in a city where there are no VCTs installed yet. Also, it makes the answers more realistic when getting participants with knowledge if not experience.

Table 4 shows the educational level of the participants: 68% of the participants had an undergraduate degree, and 12% were postgraduates. Only 20% of them were below that. Most of the drivers had more than one car trip per day which means at least seven trips per week. Only 7% of them made fewer trips than that. In a country such as UAE, this result is expected because the primary mode of transportation is by private car.

Table 3: Participant nationalities

Nationality	Total participants	Percentage
Local (Emirati)	163	32%
Resident (expatriate)	328	66%
Tourist	9	2%

Regarding gender, 62% of the participants were male, and 38% were female. The total number and percentage of gender distribution are listed in **Table 5**. This number is near the statistics found by the Department of Statistics and Community Development in Sharjah (DSCD) in 2015, where statistics showed that males made up 66% and females made up 34%. Statistics from Dubai Statistics 2016 show the male population there to be 70% of the total population. The difference between Sharjah and Dubai statistics can be explained, as, in Dubai, more labourers and workers are in most cases male workers living as singles in Dubai. **Figure 16** compares percentages.

Table 4: Participant Educational Level

Level	Total participants	Percentage
Secondary/high school	102	20%
Undergraduate/bachelor's degree	339	68%
Postgraduate/master's degree	59	12%
Doctoral degree	0	0%

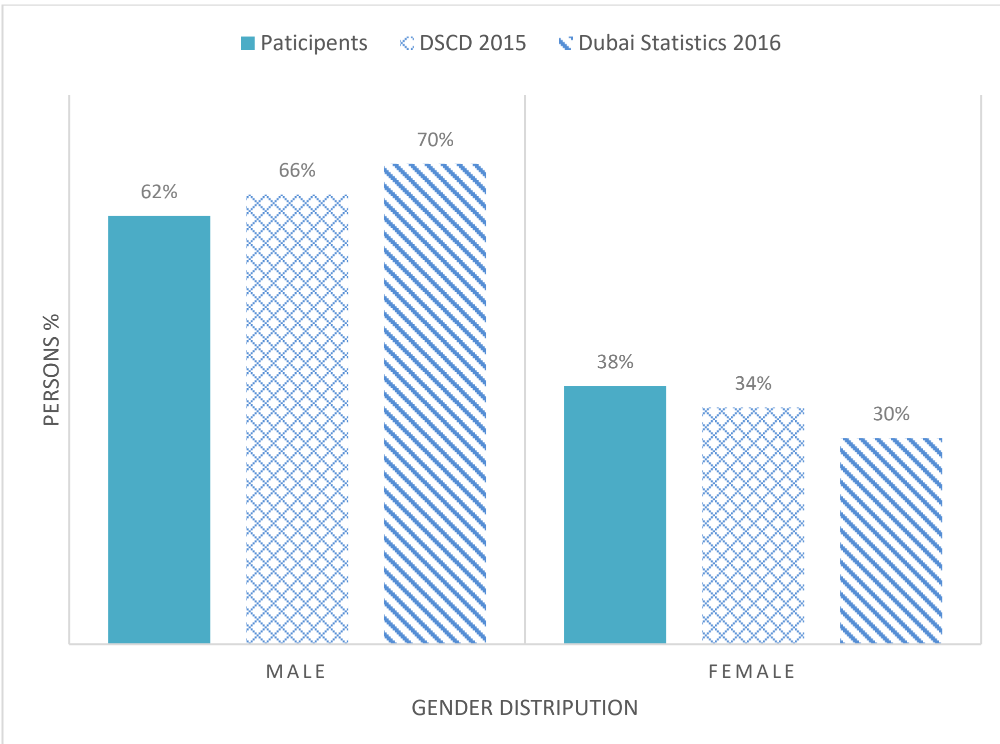


Figure 16: Comparison between Gender Distribution of Participants in VCT Survey, DSCD 2015, and Dubai Statistics 2016

Table 5: Participant Gender Distribution

Gender	Total participants	Percentage
Male	312	62%
Female	188	38%

Most of the participants fell in the 18-24 age group. Around 54% of them were in that group. While 21% of them were between 25-34, 14% of them were between 35-44. Only 7% were between 45-54 and 4% were older than 54 (**Table 6**). The age distribution of participants is different from the real distribution of the area population. **Figure 17** shows a comparison between the participant age distribution and Dubai population statistics for 2016. Dubai Statistics 2016 categorised age into 16 groups, each group of 5 years starting from 0 to 75 years old. To compare those 16 groups with the five groups in this study, these modifications have been applied to the data from Dubai Statistics 2016:

- Three groups were excluded (0-4, 5-9, and 10-14). Those groups are not part of the current study.
- The total population in group 15-19 has been divided by five based on the assumption that the ages are equally distributed. Then two portions of the population were added to the 20-24 group as if those portions represent the age of 18 and 19. The total number created is assumed to represent the group of 18-24 years.
- Each of the two groups has been combined from 25 to 54 years.
- All groups from 55 and above have been summed up to create the last group (55>).

Table 6: Participant age distribution

Age	Total participants	Percentage
18-24	270	54%
25-34	103	21%
35-44	68	14%
45-54	37	7%
55>	22	4%

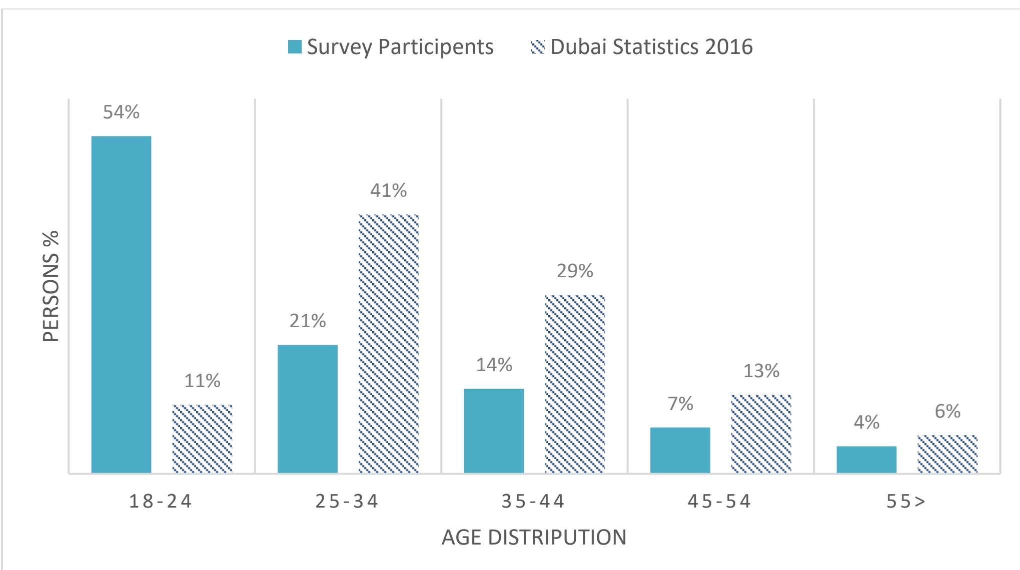


Figure 17: Comparison Between Survey Participants and Dubai Statistics 2016 Age Distribution

Table 7: Participant Number of Trips/Day

Number of Trips/Day	Total participants	Percentage
<1	35	7%
1-2	217	43%
3-4	165	33%
>5	83	17%

Red Countdown Timer

Overall, most of the drivers thought that the SCT had a positive impact. More than 80% of the drivers thought that the red countdown timer could relieve frustration from stopping for long, unknown periods of time during the red interval, especially when a signal has long cycle times. About 71% of the drivers thought that the timer could result in better use of their waiting time during the red interval, and 85% of the drivers indicated that it could assist them to promptly proceed through the intersection when the signal turns green thus reducing their start-up lost time. The only issue where the answers were distributed more evenly is when drivers were asked if they would turn off the engine while waiting in the queue. Only 34% agreed to turn off the engine while 32% refused to do so. This result was unsurprising given that vehicles in this region are not equipped yet with this technology, in addition to the fact that drivers would not want to turn off their car engines to keep on the air-conditioning inside the car due to the extremely hot conditions and encouraged by the low fuel price. The results related to red countdown timers are shown in **Table 8.**

Table 8: Questionnaire results related to the red countdown timer

Questions rating	Relieve frustration	Better use of waiting time	Turn off the engine	Assist in proceeding promptly
Strongly agree	41%	32%	14%	38%
Agree	41%	39%	20%	47%
Neutral	12%	18%	28%	12%
Don't agree	3%	7%	24%	2%
Str. Don’t agree	1%	1%	9%	1%
Don't know	2%	3%	6%	1%

Green Countdown Timer

As for the green countdown timer, about 87% of the drivers thought positively, and nearly 3% thought negatively about them, whereas about 79% of the drivers thought positively and nearly 5% thought negatively about the red countdown timer. This result indicates that there is no significant difference between the perception of drivers toward the red and the green countdown timers. The results related to green countdown timers are shown in **Table 9**.

Table 9: Questionnaire results related to the green countdown timer

Questions rating	Assist better judgment to stop	Confidence in driving through
Strongly agree	45%	44%
Agree	43%	43%
Neutral	8%	10%
Don't agree	2%	1%
Strongly don’t agree	1%	1%
Don't know	1%	1%

4.2.3. Inferential statistics

In this section, the results are analysed after categorising the survey responses based on the demographic and general question answers from the participants. The whole survey has been divided into five categories (residential status, gender, age group, familiarity, and car trips). Statistical validity on the significance of group differences was investigated using chi-square test statistic at 95% confidence level.

Residential status

This category contains three subcategories. It is useful to check if there is a difference between answers given by Emiratis and residents. **Table 10** shows the results collected from Emiratis. They were around 32% of the total participants. Of Emiratis, 94% made at least one car trip per day, 96% of them were familiar with SCTs, 85% of them thought that SCTs could relieve frustration during stop time, 67% of them thought that they could use the waiting time in a better way, while 90% agreed that SCTs could reduce the start-up lost time. Regarding stopping at the right time, 93% agreed in this matter. Regarding confidence, 94% of them thought that they would be more confident driving during the green time. Regarding the question related to turning off the engine, only 24% agreed, and around 40% said they do/would not. About 35% of them were either neutral or don’t know. There is a significant difference between their opinions about red countdown timers and green countdown timers. Emiratis were more favourable toward green countdown timers.

Table 10: Emirati participant VCT survey results

Gender		Age		Education Level		Familiar		Car Trips/Day	
Male	61%	**18-24**	14%	**High School**	32%	**yes**	96%	**1**	4%
Female	39%	**25-34**	36%	**Undergraduate**	51%	**no**	4%	**1-2**	42%
		35-44	29%	**Postgraduate**	17%			**3-4**	40%
		45-54	12%					**4-5**	14%
		55	9%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	45%	41%	10%	47%	54%	59%
Agree	40%	26%	14%	43%	39%	35%
Neutral	7%	18%	23%	7%	5%	6%
Don't agree	4%	9%	31%	1%	1%	0%
St Don't agree	1%	2%	10%	0%	0%	0%
Don't know	2%	4%	12%	2%	1%	1%

Non-Emirati participants were around 66%. **Table 11** shows the results from residents (Non-Emirates). Of the 66%, 92% of them made at least one trip per day, 86% of them were familiar with VCTs, 81% of them thought that VCTs could relieve frustration during the stop time, 73% of them thought that they could use the waiting time in a better way, while 81% agreed that it could reduce start-up lost time. Regarding stopping at the right time, 85% agreed in this matter. Regarding confidence, 84% of them thought that they would be more confident driving during the green time. Regarding the question related to turning off the engine, only 38% agreed, and around 28% said they do/would not. About 35% of them were either neutral, or they do not know.

Table 11: Resident participant VCT survey results

Gender		Age		Education Level		Familiar		Car Trips/Day	
Male	62%	**18-24**	74%	**High School**	14%	**yes**	86%	**1**	8%
Female	38%	**25-34**	13%	**Under Graduate**	77%	**no**	14%	**1-2**	45%
		35-44	6%	**Post Graduate**	9%			**3-4**	29%
		45-54	5%					**4-5**	18%
		55	2%						

Questions rating	Frustration	waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	134	107	41	33%	40%	37%
Agree	123	116	47	48%	45%	47%
Neutral	39	52	91	15%	10%	12%
Don't agree	10	24	81	2%	2%	2%
St Don't agree	1	4	30	1%	1%	1%
Don't know	5	9	22	1%	2%	2%

There was a significant difference in 5 questions out of 6 between the Emiratis and non-Emiratis. The first question was the only question which doesn't have a significant difference. The most prominent difference was in the question regarding turning the engine off, as shown in **Figure 18**. Residents were more positive regarding that. In general, Emiratis were more favourable toward VCTs, especially

the green stage, except the question of turning off the engine. The responses on red countdown timers showed less difference than for green countdown timers.

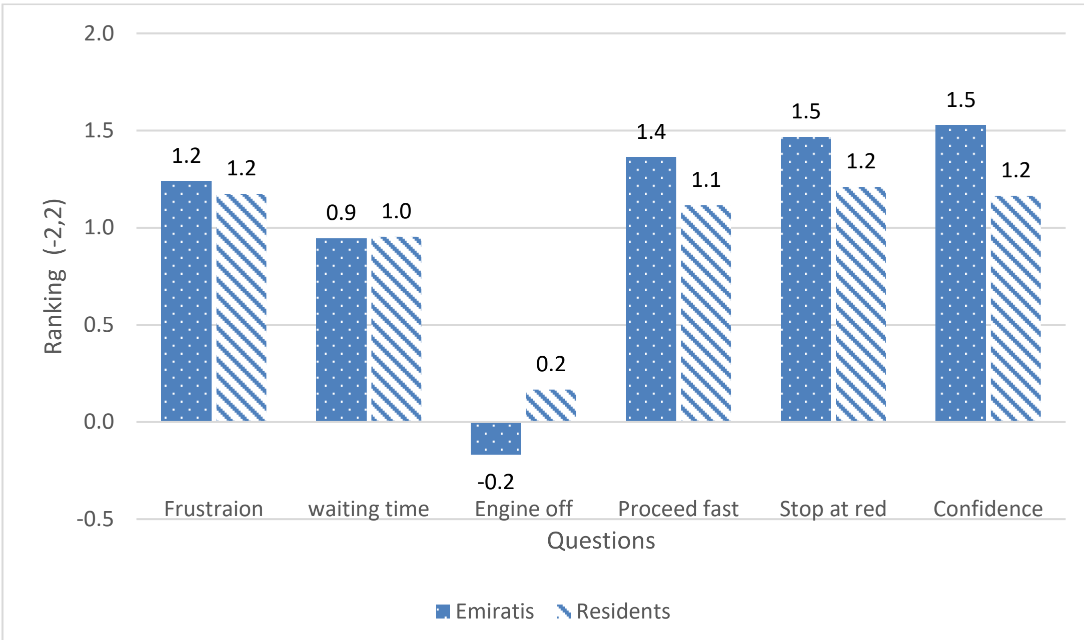


Figure 18: Comparison between Emiratis and resident participants opinion scaling regarding VCTs

Gender

Table 12 shows the results from male participants: 32% of them were Emiratis and 65% were residents; 70% of them were age 18-34; around 90% were familiar with VCTs; 95% made at least one trip per day. More than 80% of them agreed that VCTs have a positive effect on relieving frustration, stopping at the right time, proceeding faster, and feeling confidence driving during the green interval. Also, 71% of them thought that they could use waiting time in a better way if they know the remaining time. Only 28% agreed to turn off the engine, while 36% disagreed in this matter. There was a significant difference between their opinions about red and green countdown timers.

Table 12: Males participant VCT survey results

Residents		Age		Education Level		Familiar		Car Trips/Day	
Local	32%	**18-24**	50%	**High School**	21%	**Yes**	89%	**1**	5%
Resident	65%	**25-34**	20%	**Under Graduate**	65%	**No**	11%	**1-2**	34%
Tourist	3%	**35-44**	17%	**Post Graduate**	14%			**3-4**	35%
		45-54	7%					**4-5**	26%
		55	6%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	43%	34%	13%	43%	50%	48%
Agree	39%	37%	15%	44%	37%	40%
Neutral	13%	17%	29%	8%	8%	10%
Don't agree	3%	8%	26%	2%	2%	1%
St don't agree	0%	1%	10%	1%	1%	0%
Don't know	2%	2%	3%	2%	2%	1%

For the female participants: 34% of them were Emiratis, and 66% were residents; 82% were age 18-34; 88% were familiar with VCTs. Findings were similar to those of male participants, and 90% of them made at least one trip per day. Similar to males, more than 80% of females agreed that VCTs have a positive impact on relieving frustration, stopping at the right time, proceeding faster, and having confidence driving during the green interval. For females, 71% thought that they could use the waiting time in a better way, and 43% agreed to turn the engine off at only 27% disagreeing which was surprising.

Table 13: Females participant VCT survey results

Residents		Age		Education Level		Familiar		Car Trips/Day	
Local	34%	**18-24**	60%	**High School**	20%	**Yes**	88%	**1**	10%
Resident	66%	**25-34**	22%	**Under Graduate**	72%	**No**	12%	**1-2**	59%
Tourist	1%	**35-44**	9%	**Post Graduate**	8%			**3-4**	29%
		45-54	7%					**4-5**	2%
		55	2%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	38%	29%	15%	29%	35%	38%
Agree	44%	41%	28%	51%	53%	47%
Neutral	11%	21%	26%	19%	10%	10%
Don't agree	3%	5%	20%	1%	1%	2%
St don't agree	1%	1%	7%	1%	1%	1%
Don't know	38%	29%	15%	29%	35%	38%

There was a significant difference between the answers from male and female respondents regarding three questions. Females were more positive than males regarding turning the engine off during wait times. On the other hand, males were more positive than females regarding proceeding in a faster way and stopping at the right time. There was no significant difference in the remaining questions.

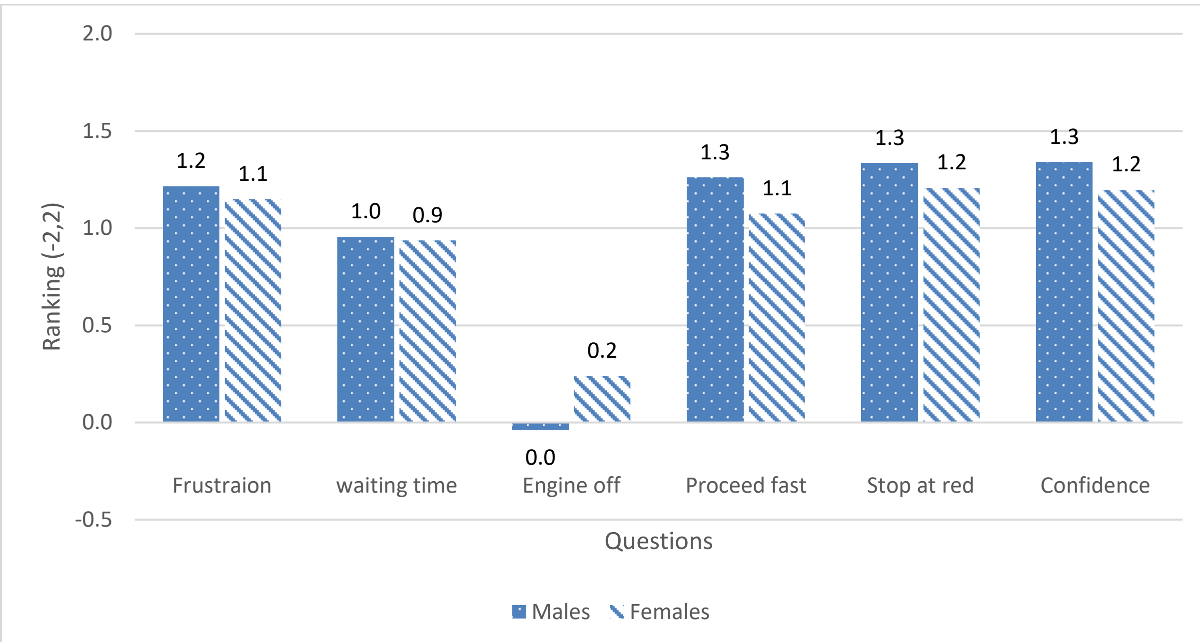


Figure 19: Comparison between males and females' participant's opinion scaling regarding VCT

Age group distribution

Age groups of respondents have been divided into four categories: 18-24 years, 25-34 years, 35-44 years, and 45 years and above.

The first category in the age group was 18-24. The demographic information of this group is shown in **Table 14**. In that age group, 84% were familiar with VCTs, and 94% made at least one trip per day. Around 75% agreed that VCTs could relieve frustration, make better use of waiting time, and enable them to proceed faster. Around 85% agreed that VCTs help them to stop at the right time before the red light starts and to feel confident driving through the green interval. Only 40% of them agreed to turn off the engine, which researchers found surprising for this age category. Only 27% did not agree to do so. This group's answers regarding red and green countdown timers are listed in **Table 14**.

Table 14: 18-24 years participant VCT survey results

Residents		Gender		Education Level		Familiar		Car Trips/Day	
Local	9%	**Male**	58%	**High School**	13%	**yes**	84%	**1**	6%
Resident	90%	**Female**	42%	**Under Graduate**	84%	**no**	16%	**1-2**	47%
Tourist	1%			**Post Graduate**	4%			**3-4**	30%
								4-5	17%

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	36%	26%	17%	32%	37%	32%
Agree	41%	46%	23%	47%	48%	51%
Neutral	15%	19%	30%	17%	10%	12%
Don't agree	4%	6%	20%	2%	3%	2%
St don't agree	1%	1%	7%	1%	1%	1%
Don't know	3%	2%	3%	1%	1%	1%

Table 15 shows the demographic statistics for the age group between 25 to 34. Most of them were familiar with VCTs. More than 90% were expert drivers who made more than one trip per day. Around 90% of them agreed that VCTs have a positive impact on relieving frustration, stopping at the right time, proceeding faster, and feeling confidence driving during the green interval; 78% of them thought that they could use the waiting time in a better way. In that age group, 36% agreed to turn off the engine, whereas the next age group level showed only 21% for age 35-44. The 25-34 age group held similar opinions and similar experiences with the previous age group of 18-24, as shown in **Table 16**. Overall, they were more favourable toward the green than red countdown timers.

There was a significant difference in the oldest group, age 45 and over. Again, they felt more favourable toward green countdown timers than red ones. This was the smallest group, only 59 participants, and most of them were males (see **Table 17**). They were familiar with VCTs and generally were expert drivers. They were the most positive group in all questions except the question regarding waiting time. Only 54% of them agreed that they could use the waiting time more effectively. The reason could be that they are not regular phone users or active in social media. Most of the participants who agreed with this question were most likely thinking of using a phone or other technology during the waiting time.

Table 15: 25-34 years participant VCT survey results

Residents		Gender		Education Level		Familiar		Car Trips/Day	
Local	56%	**Male**	59%	**High School**	19%	**yes**	92%	**1**	9%
Resident	41%	**Female**	41%	**Under Graduate**	55%	**no**	8%	**1-2**	41%
Tourist	3%			**Post Graduate**	25%			**3-4**	37%
								4-5	14%

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	50%	42%	13%	43%	56%	61%
Agree	39%	36%	23%	49%	33%	25%
Neutral	9%	14%	24%	7%	8%	13%
Don't agree	0%	4%	26%	0%	0%	0%
St don't agree	1%	1%	7%	1%	1%	0%
Don't know	2%	4%	7%	1%	2%	1%

There were mixed results and answers between those age groups. There was a significant difference between the first two age groups regarding all green timer questions. In comparison between the youngest group and the 35-44 years group, there was a significant difference in all questions. Again, the older group respondents were more positive regarding all questions except the third question. This was repeated in comparison with the oldest group as well.

Table 16: 35-44 years participant VCT survey results

Residents		Gender		Education Level		Familiar		Car Trips/Day	
Local	69%	**Male**	76%	**High School**	35%	**yes**	96%	**1**	7%
Resident	29%	**Female**	24%	**Under Graduate**	46%	**no**	4%	**1-2**	31%
Tourist	1%			**Post Graduate**	19%			**3-4**	43%
								4-5	19%

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	56%	46%	16%	46%	49%	57%
Agree	31%	25%	4%	43%	43%	37%
Neutral	9%	18%	29%	6%	7%	3%
Don't agree	4%	10%	24%	3%	0%	1%
St don't agree	0%	0%	15%	0%	0%	0%
Don't know	0%	1%	12%	3%	1%	1%

In a comparison between the second group (25-34 years) and the third group (35-44), there was a significant difference in the third question only. The younger group was positive regarding that question. This comparison also repeated between the third and fourth age group. The last comparison was between the second age group and the oldest group. The responses showed that there is a significant difference between their answers about the first, second, and fourth questions. Those questions are related to red countdown timers. Otherwise, they were similar in opinions regarding green countdown timers.

Table 17: 45+ years participant VCT survey results

Residents		Gender		Education Level		Familiar		Car Trips/Day	
Local	59%	**Male**	71%	**High School**	41%	**yes**	93%	**1**	7%
Resident	37%	**Female**	29%	**Under Graduate**	42%	**no**	7%	**1-2**	46%
Tourist	3%			**Post Graduate**	17%			**3-4**	29%
								4-5	19%

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	34%	29%	2%	46%	54%	56%
Agree	56%	25%	17%	47%	37%	42%
Neutral	7%	22%	20%	7%	5%	2%
Don't agree	2%	14%	36%	0%	0%	0%
St don't agree	0%	3%	14%	0%	2%	0%
Don't know	34%	29%	2%	46%	54%	56%

By looking at **Figure 20,** which shows the comparison ranking between all age groups, it can be noticed that the distribution in the first two questions is the same. The youngest and the oldest groups have the lowest ranking, and the middle age groups were more positive toward most of the questions. On the other hand, the last three questions were similar in distribution. Answers were more positive as respondents got older. In contradiction, the third question runs precisely in another way, where the younger groups were more positive.

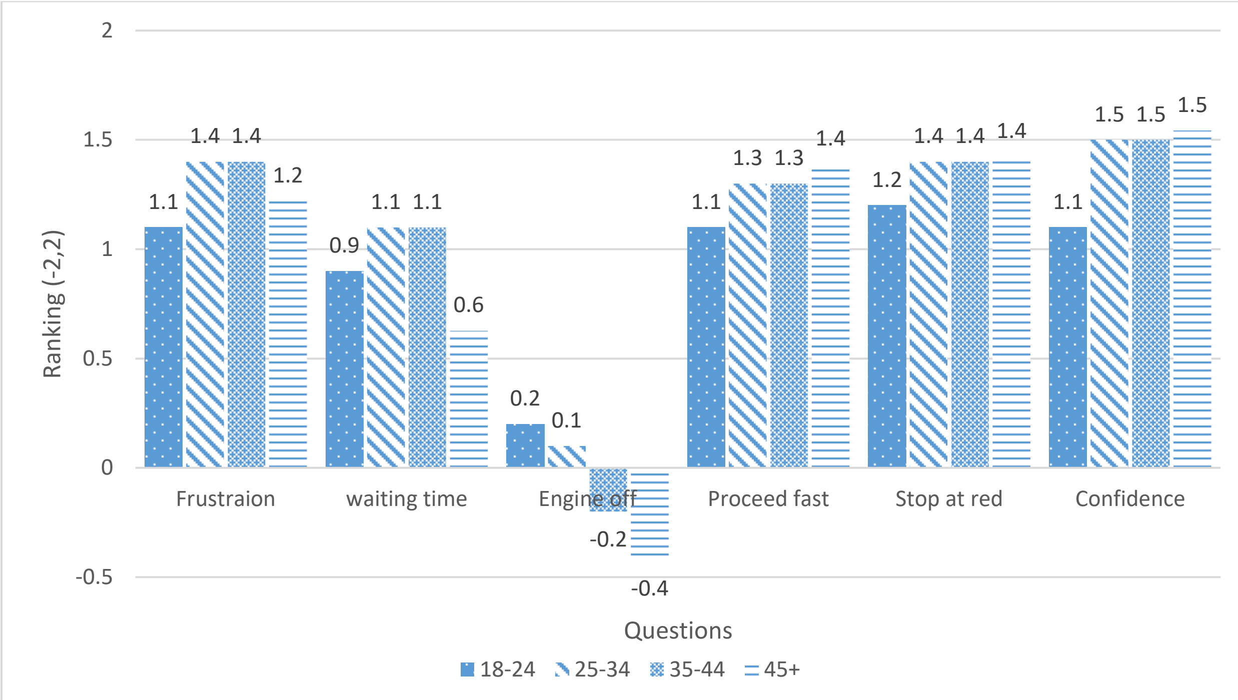


Figure 20: Comparison between age groups participants opinion scaling regarding VCT

Number of trips per day

This question was asked to see if there is any difference between various driver levels. The first group was drivers who made less than one trip per day (see **Table 18**). In a country such as the UAE, cars are the most frequent mode used for all types of travel. The low cost of fuel, long distances, and weak public transport system may be the reason behind it. Because of that, most drivers made more than one trip per day, and respondents in this category were fewer compared to others. In this group, 17% were Emiratis, 9% were tourists who "in most cases" don't drive in a "foreign country" and the remaining were other residents. Gender was distributed almost equality. Although they were the least-time drivers, 83% of them were familiar with VCTs. They were positive about all questions.

Table 18: Participants with less than one trip/day VCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	17%	**18-24**	49%	**High School**	23%	**Male**	46%	**Yes**	83%
Resident	74%	**25-34**	26%	**Under Graduate**	66%	**Female**	54%	**No**	17%
Tourist	9%	**35-44**	14%	**Post Graduate**	11%				
		45-54	11%						
		55	0%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	46%	14%	20%	40%	40%	46%
Agree	40%	60%	26%	37%	43%	40%
Neutral	11%	20%	37%	17%	14%	11%
Don't agree	0%	3%	11%	3%	0%	0%
St don't agree	3%	0%	0%	3%	3%	0%
Don't know	0%	3%	6%	0%	0%	3%

The second group of drivers made 1 to 2 trips per day (see **Table 19**). They had almost the same demographic characteristics as the first group. In a comparison between their opinions, there was no significant difference between these two categories in all questions. The second group was a little more positive in most of the questions, especially the third question.

Table 19: Participants with 1-2 trips/day VCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	31%	**18-24**	59%	**High School**	21%	**Male**	49%	**Yes**	86%
Resident	67%	**25-34**	19%	**Under Graduate**	72%	**Female**	51%	**No**	14%
Tourist	1%	**35-44**	10%	**Post Graduate**	7%				
		45-54	6%						
		55	6%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	34%	27%	13%	34%	37%	42%
Agree	47%	37%	19%	48%	49%	44%
Neutral	13%	23%	30%	13%	10%	12%
Don't agree	3%	8%	24%	2%	2%	1%
St don't agree	0%	1%	8%	0%	0%	0%
Don't know	3%	4%	6%	2%	2%	1%

The third group was drivers with 3 to 4 trips per day (see **Table 20**). Two-thirds of this group were male. More than 90% of them were familiar with VCTs. It was the group with the most Emiratis (40%). This may relate to the reason this group gave the most negative results regarding the third question. More than 80% of them were positive and agreed to four questions out of six. The question related to relieving the frustration, proceeding in a faster way, stopping at the right time before the red light, and feeling confidence driving during the green interval all received positive responses. Around 75% of them agreed with the question of better using waiting time. The only question which more than 40% of them disagreed with was the third question.

In a comparison between the first group and this group, there was only a significant difference in question number three. However, in compassion with the second group, there was a significant difference in second, third, and fourth questions. This group was more favourable toward all questions except the third and sixth questions.

Table 20: Participants with 3-4 trips trip/day VCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	40%	**18-24**	49%	**High School**	22%	**Male**	67%	**Yes**	91%
Resident	58%	**25-34**	23%	**Under Graduate**	62%	**Female**	33%	**No**	9%
Tourist	2%	**35-44**	18%	**Post Graduate**	15%				
		45-54	7%						
		55	3%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	42%	35%	8%	33%	45%	39%
Agree	41%	39%	21%	52%	41%	47%
Neutral	11%	18%	24%	14%	9%	9%
Don't agree	4%	7%	30%	0%	2%	3%
St don’t agree	1%	1%	11%	1%	2%	1%
Don't know	1%	1%	6%	0%	1%	1%

The last and most expert group was drivers with more than five trips per day (see **Table 21**). Those can spend most of their day travelling from one point to another. They were the group most familiar with VCTs (93%). It is noticeable that as they make more trips, they have more knowledge about the VCT. Almost all of them were males. More than 85% of them were educated at least as an undergraduate. They were positive regarding most of the questions. Around 90% of them agreed that VCTs could help in proceeding faster, reducing the start-up lost time, improving confidence driving through during the green interval, and stopping at the right time to prevent red-light violations. More than 80% of them agreed that VCTs could relieve frustration and better use waiting time. More than 40% of them agreed to turn off the engine, which is a good indication of the expert drivers.

Table 21: Participants with more than five trips/day VCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	28%	**18-24**	54%	**High School**	13%	**Male**	96%	**Yes**	93%
Resident	72%	**25-34**	17%	**Under Graduate**	69%	**Female**	4%	**No**	7%
Tourist	0%	**35-44**	16%	**Post Graduate**	18%				
		45-54	8%						
		55	54%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	57%	51%	25%	54%	64%	58%
Agree	25%	34%	17%	35%	31%	34%
Neutral	12%	7%	27%	5%	1%	6%
Don't agree	4%	4%	14%	2%	1%	0%
St don’t agree	1%	1%	10%	1%	1%	1%
Don't know	1%	4%	7%	2%	1%	1%

In a comparison between the first group and this group, there was a significant difference related to questions number two and five. In both questions, the most frequent drivers were more positive. In a comparison between the second group and this group, there was no significant difference in their opinions regarding the third and last question. Again, this group was more positive in all questions. Comparing the third group with this group, there was a significant difference in questions two, three, and four. Logically, there should not be a big difference between the last two groups, but their opinions may vary based on other factors as well.

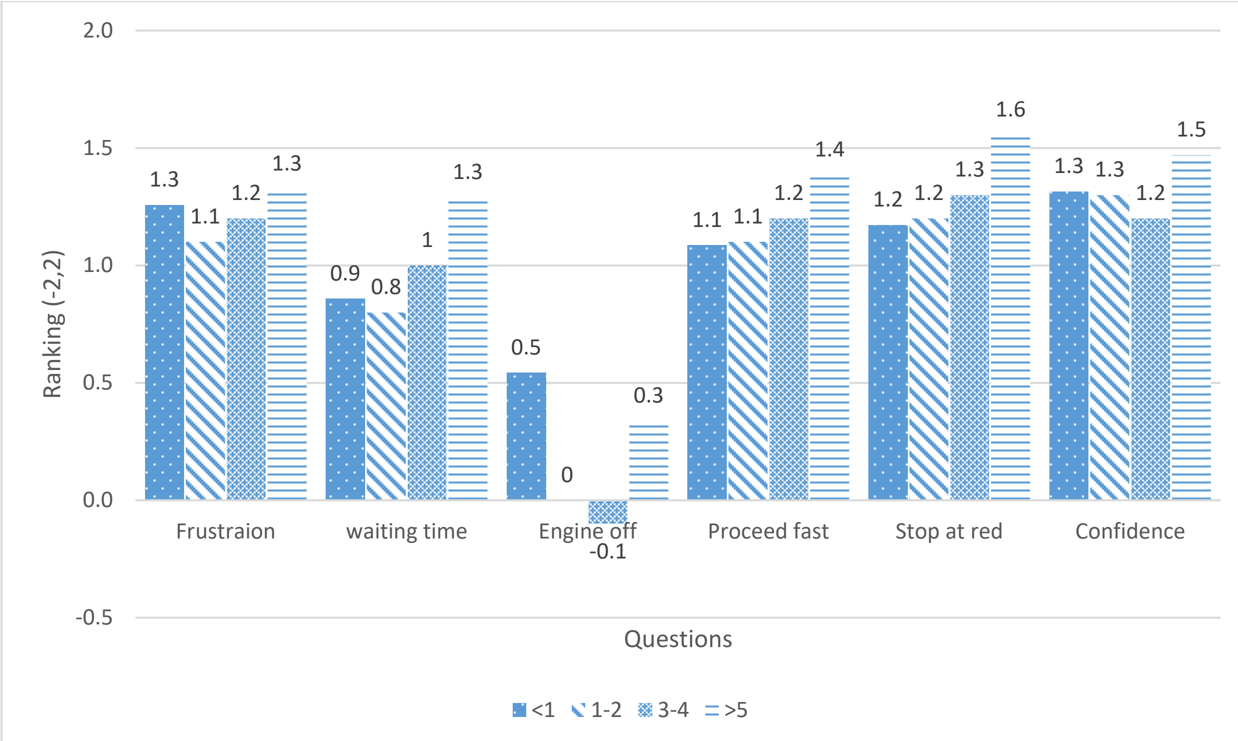


Figure 21: Comparison of participants with different car trips per day

Educational level

Educational level has been divided into three categories: drivers with high school level and below, undergraduates, and postgraduates. In the first category, 90% of the participants were familiar with VCTs and made at least one trip per day. **Table 22** shows the demographic characteristics and results from this category and their opinions regarding the red and green countdown timers. They were positive regarding most of the questions except the third question. Question two, which is about using the waiting time during the red interval, gets the least positive attention after the third question. One reason could be that more than 45% of this category were over 35 years old. That age category, as mentioned in previous sections, was negative on this question. This category was more favourable toward the green countdown timer than the red countdown timer.

Table 22: Participants with high school education and below VCT survey results

Residents		Age		Familiar		Gender		Car Trips/Day	
Local	51%	**18-24**	33%	**Yes**	90%	**Male**	63%	**1**	8%
Resident	46%	**25-34**	20%	**No**	10%	**Female**	37%	**1-2**	45%
Tourist	3%	**35-44**	24%					**3-4**	36%
		45-54	14%					**4-5**	11%
		55	10%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	40%	29%	9%	38%	50%	50%
Agree	41%	28%	15%	46%	36%	42%
Neutral	14%	26%	25%	10%	10%	7%
Don't agree	2%	9%	25%	3%	1%	0%
St don’t agree	1%	2%	16%	1%	1%	1%
Don't know	2%	5%	11%	2%	2%	0%

The second category of educational level was drivers with undergraduate education. Of this category, 67% fell in the 18-24 years age group and 60% of them were males. **Table 23** shows the demographic characteristics of this group and their opinions regarding the red and green countdown timers. They were positive regarding all questions. In a comparison between this group and the previous educational group, there was a significant difference in questions two and three. In both questions, the more educated group were more positive regarding those questions.

Table 23: Participants with undergraduate education VCT survey results

Residents		Age		Familiar		Gender		Car Trips/Day	
Local	24%	**18-24**	67%	**Yes**	88%	**Male**	60%	**1**	7%
Resident	74%	**25-34**	17%	**No**	12%	**Female**	40%	**1-2**	46%
Tourist	1%	**35-44**	9%					**3-4**	30%
		45-54	5%					**4-5**	17%
		55	2%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	39%	31%	15%	37%	43%	41%
Agree	43%	43%	22%	47%	45%	44%
Neutral	12%	18%	29%	14%	8%	11%
Don't agree	4%	6%	24%	1%	2%	2%
St don’t agree	0%	1%	7%	0%	1%	0%
Don't know	2%	2%	4%	1%	1%	1%

The last category was drivers with postgraduate education. Almost all of them were familiar with VCTs. **Table 24** shows the demographic characteristics of this group. They were confident regarding all questions related to both red and green countdown timers. In a comparison between this group and the first and second groups, there was not a significant difference between them in all questions. It can be concluded that the educational level of drivers may not affect their opinions about VCTs. **Figure 22** shows the comparison between different educational level participants in opinions regarding VCTs.

Table 24: Participants with postgraduate education for VCT surveys

Residents		Age		Familiar		Gender		Car Trips/Day	
Local	47%	**18-24**	17%	**Yes**	92%	**Male**	75%	**1**	7%
Resident	49%	**25-34**	44%	**No**	8%	**Female**	25%	**1-2**	25%
Tourist	3%	**35-44**	22%					**3-4**	42%
		45-54	10%					**4-5**	25%
		55	7%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	54%	44%	17%	37%	46%	51%
Agree	29%	34%	19%	47%	44%	36%
Neutral	10%	7%	27%	8%	7%	8%
Don't agree	3%	10%	22%	3%	0%	2%
St don't agree	2%	2%	7%	2%	2%	2%
Don't know	2%	3%	8%	2%	2%	2%

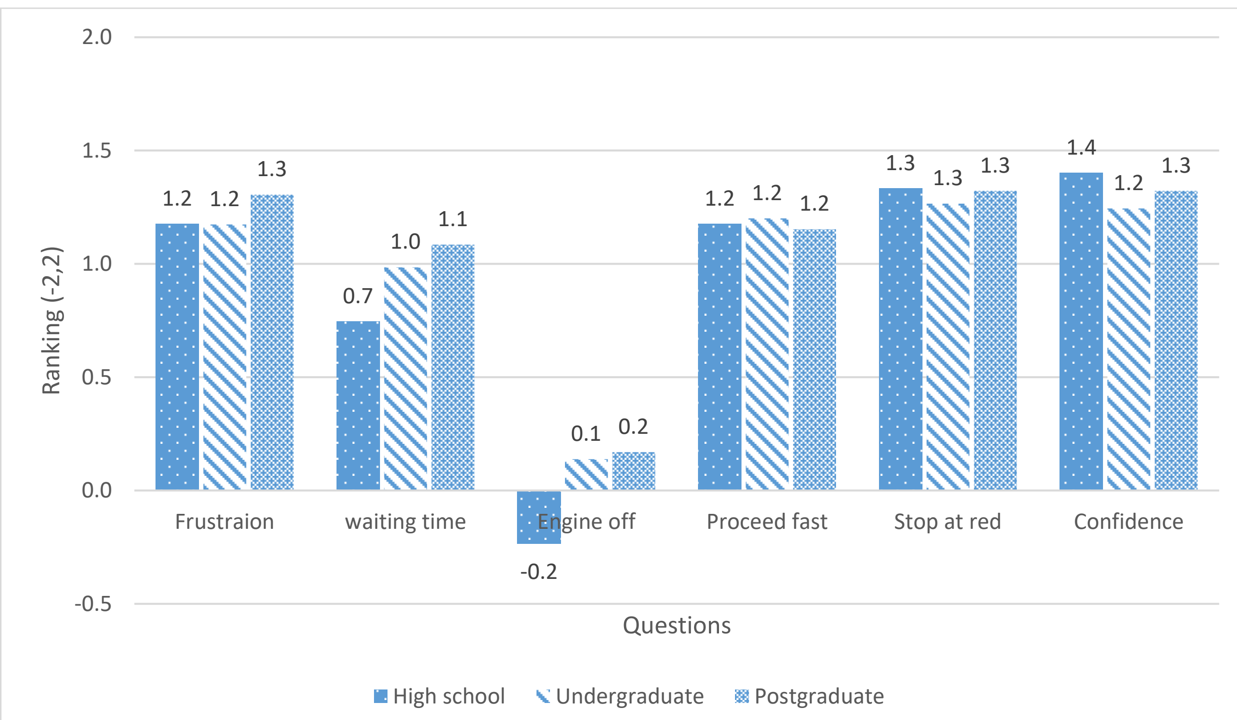


Figure 22: Comparison between the different educational level of participants opinion regarding VCT

Familiarity

The next category is familiarity with VCTs. Although most of the participants (89%) were familiar with the system, it is useful to check whether there were differences between their answers, and which demographics were not familiar with the system. A brief explanation has been given to those who did not know VCTs so that they could answer the questions.

Of the participants who were familiar with VCTs, 35% were Locals, and 64% were residents. Most of them made many trips per day, and it therefore logical that they would be familiar with VCTs. Whereas 11% of the non-familiars made less than one trip per day, and 53% of them made 1-2 trips per day. Most of the non-familiars were residents (79%), and around 9% were tourists. This breakdown means that most of the locals were familiar with the system even if they were living in a city not having the system installed. **Table 25** and

Table 26 shows the demographic characteristics and answers from participants familiar and unfamiliar with VCTs, respectively.

Table 25: VCT survey results of participants who were familiar with VCT

Residents		**Age**		**Education Level**		**Gender**		**Car Trips/Day**	
Local	35%	**18-24**	51%	**High School**	21%	**Male**	63%	**1**	7%
Resident	64%	**25-34**	21%	**Under Graduate**	67%	**Female**	37%	**1-2**	42%
Tourist	1%	**35-44**	15%	**Post Graduate**	12%			**3-4**	34%
		45-54	8%					**4-5**	17%
		55	5%						

Questions rating	**Frustration**	**Waiting time**	**Engine off**	**Proceed fast**	**Stop at red**	**Confidence**
Strongly Agree	43%	35%	14%	40%	48%	48%
Agree	40%	37%	20%	46%	41%	41%
Neutral	12%	17%	28%	12%	8%	9%
Don't agree	3%	7%	24%	1%	1%	1%
St don’t agree	1%	1%	9%	1%	1%	1%
Don't know	1%	2%	5%	1%	1%	1%

Of the participants who were unfamiliar with the system, most agreed to the benefits of VCTs, even though most of their answers were “Agree” not “Strongly agree” as with the participants who were familiar, which make sense. It is logical to receive more certain answers from people familiar with the system. From **Figure 23**, it can be observed that the participants who were familiar with VCTs were more positive in all questions except the third question. There was a significant difference between all questions except the third question.

Table 26: VCT survey results participants who were not familiar with VCT

Residents		Age		Education Level		Gender		Car Trips/Day	
Local	12%	**18-24**	74%	**High School**	18%	**Male**	60%	**1**	11%
Resident	79%	**25-34**	14%	**Under Graduate**	74%	**Female**	40%	**1-2**	53%
Tourist	9%	**35-44**	5%	**Post Graduate**	9%			**3-4**	26%
		45-54	5%					**4-5**	11%
		55	2%						

Questions rating	Frustration	Waiting time	Engine off	Proceed fast	Stop at red	Confidence
Strongly Agree	28%	11%	14%	21%	19%	16%
Agree	51%	56%	19%	53%	60%	60%
Neutral	11%	26%	30%	16%	12%	19%
Don't agree	2%	2%	21%	4%	5%	2%
St don't agree	0%	0%	5%	0%	0%	0%
Don't know	9%	5%	11%	7%	4%	4%

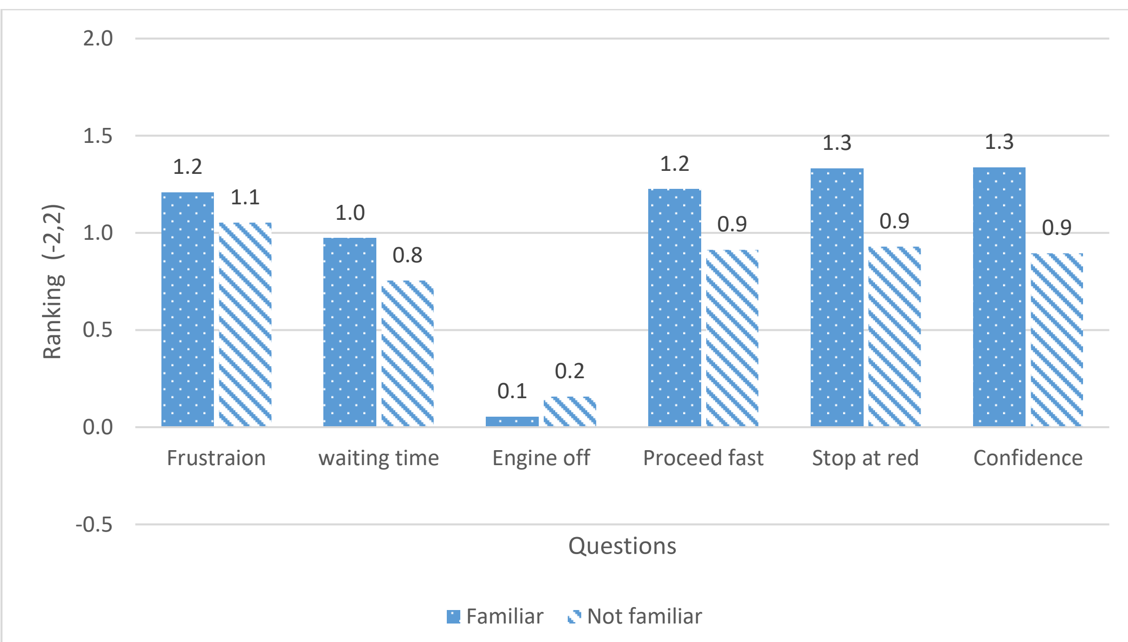


Figure 23: Comparison between participants who were familiar and not familiar about VCTs

4.3. Statistical analysis of pedestrian’s survey

4.3.1. Questionnaire structure and questions

The objective of the statistical survey for pedestrians focused on pedestrians’ comprehension and preferences toward PCTs in the UAE. Survey questions were designed to study five categories of questions as shown in **Error! Reference source not found.**:

- Question A to G: Demographic and General Questions
- Question 1 – 2: General Question about PCTs
- Question 3 – 4: Red Countdown Timer
- Question 5 – 6: Green Countdown Timer
- Comments box: Open-ended question

The questionnaire consisted of 13 questions and a comment box in both English and Arabic languages created using Google Forms. The questionnaire surveys were carried out at sites where a PCT was installed and at sites where there was no PCT. The rest of the questionnaire was collected online. The questionnaire was designed based on similar opinion surveys reviewed in the literature. It aimed to have an overall idea of pedestrians’ opinions of countdown signals regarding preference, safety, compliance, comfort level, speed, and crossing behaviour.

For onsite surveys, as soon as people finished crossing, some were requested to take part in the survey. Interviews were conducted at two separate sites, one at a site with a countdown timer and one at a site without a countdown timer. Both questionnaires had the same set of questions except that the questionnaire for the site with a countdown timer had an added question (Question 6) to understand pedestrians’ changes in behaviour with the instalment of countdown signals. The questionnaire survey was conducted in a time-span of two months. A total of 500 surveys were collected; 97 from the control site (without) and 178 from the site (with).

Demographic and a general question about PCTs

Questions 1 and 2 were general questions about the PCT. The questions were:

1. Would you prefer countdown timers at pedestrian signals?
2. Do you think countdown timers at pedestrian signals are safer?

Question 1 was about the preference of the pedestrian of having the PCT or not. Question 2 was about the safety which the pedestrian believed PCTs could provide for pedestrians; whether they thought that intersections with a PCT are safer than those without it.

Red countdown timer questions

Two questions were related to red countdown timers:

3. Would you avoid crossing at red lights if you knew the remaining time?
4. Do you think that countdown timers at pedestrian signals relieve frustration from stopping for long and uncertain amounts of time during the red signal?

Question 3 was about red-light violations and whether pedestrians would stop and wait until the signals turn to green if a PCT informs them. Question 4 was about relieving frustration from stopping for uncertain and extended times during the red stage.

Green countdown timer questions

Two questions were related to green countdown timers:

5. Do you think that countdown timers at pedestrian signals assist better judgment to move faster or slower depending on the time remaining?
6. How did the countdown timers at pedestrian signals influence your crossing behaviour?

Question 5 was about changing walking speed depending on the remaining green time. Question 6 was a general question about the person's opinion regarding the effect of the PCT on their crossing behaviour. They had a choice to choose more than one answer based on their opinion. The answers were about their behaviour while crossing and using the PCT. The answers were whether it could help them go faster, go slower, stop, or wait if they know the remaining time, have the confidence to cross or, last choice, if it did not change anything in their behaviour. Question 6 was asked only on-site at the intersection using a PCT.

4.3.2. Descriptive statistics

Demographic and general questions

About 94% of the pedestrian respondents were residents, and only 5% were UAE nationals as shown in **Table 27**. This was not surprising given that UAE nationals rarely use pedestrian crossings. Since nearly half of the questionnaires were directly taken on the site where a PCT was installed, nearly all (about 97%) of the pedestrians were familiar with the device.

Table 27: Participants in PCT survey nationalities

Nationality	Total participants	Percentage
Local (Emirati)	27	5%
Resident (expatriate)	468	94%
Tourist	5	1%

Of the participants, 60% were male, and the remaining were female as shown in **Table 28**. The comparison between the participant gender distribution using DSCD 2015 and Dubai Statistics 2016 is illustrated in **Figure 24**. Educationally, 68% of the participants were undergraduates, and 22% were postgraduates. Only 10% of them were below undergraduate level. The educational level of the participants is shown in **Table 29**. About 80% of the pedestrians indicated that they used the crossing at least once per week (**Table 30**).

Table 28: Participant gender distribution

Gender	Total participants	Percentage
Male	300	60%
Female	200	40%

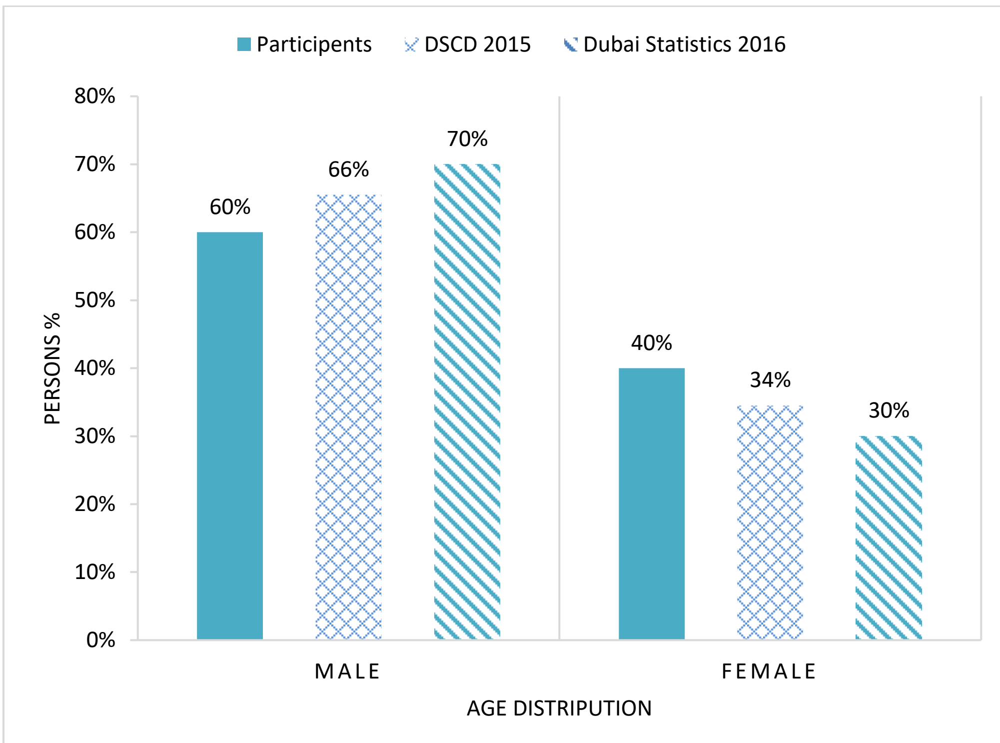


Figure 24: Comparison Between Gender Distribution of Participants in PCT Survey, DSCD 2015, and Dubai Statistics 2016

Table 29: Participant educational level

Level	Total participants	Percentage
Secondary/High School	51	10%
Undergraduate/Bachelor Degree	342	68%
Postgraduate/Master Degree	104	21%
Doctoral Degree	3	1%

Table 30: Participants number of trips/day

Number of Trips/week	Total participants	Percentage
<1	100	20%
1-3	167	33%
4-6	103	21%
>6	130	26%

Most of the participants fell in the 18-24 age group. Around 37% of them were in that group, while 28% of them were between 25-34 and 19% of them were between 35-44. Only 11% were between 45-54 and 5% were older than 54 (**Table 31**). In the pedestrian survey, the age group of the participants was better distributed comparing with vehicle surveys. However, still, there was a significant difference especially in the first three categories as shown in **Figure 25**. It is not surprised to get that, because usually, the people who use a particular pedestrian crossing could be from a typical age or educational level depending on the location of the pedestrian crossing. For example, if the crossing is near a school, then most of the users could be students.

Table 31: Participant age distribution for pedestrian survey

Age	Total participants	Percentage
18-24	185	37%
25-34	141	28%
35-44	94	19%
45-54	56	11%
55>	24	5%

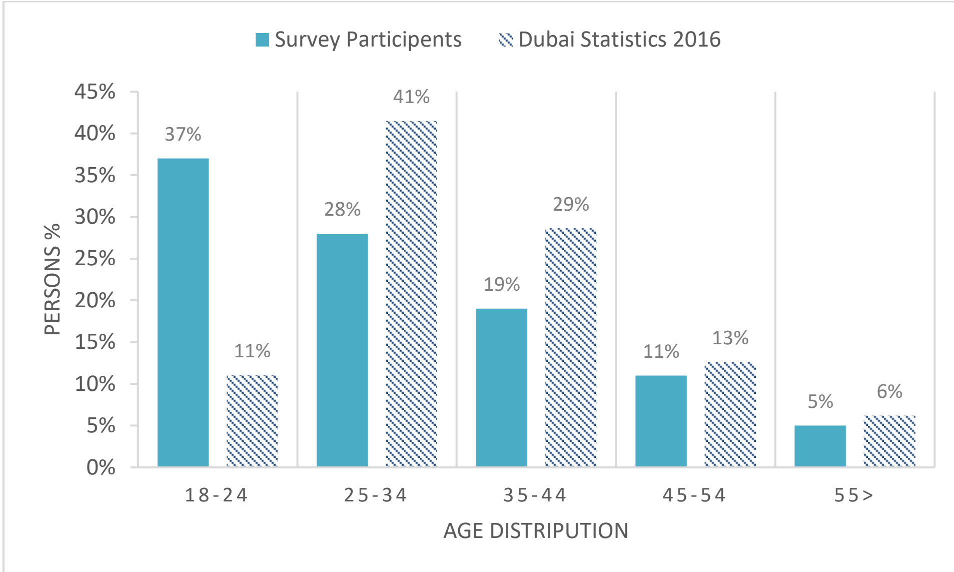


Figure 25: Comparison Between Survey Participants in PCT Survey and Dubai Statistics 2016 Age Distribution

General questions about PCTs

The first general question asked was whether pedestrians preferred PCTs at pedestrian crossings. Most respondents (87%) agreed and recommended the installation of PCTs; only 2% did not agree. The reason can be found in the comments left by those who thought that the PCT could mislead the pedestrian so that they behave wrongly at the crossing. This led to the 2% who thought that the counter could not be safe when they answered the second question about safety, whereas 89% thought that it could be safer for the pedestrian to cross with the help of the timers as shown in **Table 32**.

Table 32: Participant answers regarding the general question about PCTs

Questions rating	Preferring PCTs at pedestrian signals	Think that PCTs are safer
Strongly agree	51%	50%
Agree	36%	39%
Neutral	9%	8%
Don't agree	1%	1%
Strongly don’t agree	1%	1%
Don't know	2%	1%

Questions related to pedestrian red countdown timers

About 80% thought that the PCT could prevent them from the crossing during a red interval since they would know the remaining time. Moreover, 80% thought that the PCT could relieve their frustration from stopping for an extended and unknown amount of time. In general, as for the red countdown timer, about 80% of the pedestrians thought positively and only 5% thought negatively about them as shown in **Table 33**.

Table 33: Participant opinion regarding pedestrian red countdown timer

Questions rating	Preventing from red-light crossing	Releasing frustration
Strongly agree	39%	38%
Agree	41%	42%
Neutral	12%	14%
Don't agree	4%	3%
Strongly don’t agree	2%	1%
Don't know	2%	2%

Questions related to pedestrian green countdown timers

As for a pedestrian green countdown timer, the vast majority of pedestrians surveyed (about 89%) agreed that it could help them make a better judgment whether to move faster or slower depending on the time remaining (**Table 34**). Overall, nearly 89% of pedestrians thought positively about the green countdown timer whereas only 1% thought negatively. The last question regarding the green countdown timer was a multiple-choice question about the change in crossing behaviour due to the presence of a PCT. The choices were:

- Made me cross when I would have waited
- Stopped and waited
- Went quicker
- Went slower
- Other

Participants were able to choose more than one answer, as those choices can be applied based on crossing position and time of arrival to the crossing. The first choice was to check pedestrian behaviour near the end of the green interval which is FDW in conventional signals. Of the participants, 21% thought that PCTs could help them cross in the last seconds of a green interval successfully. This finding should lead to increased capacity and better use of the green time. The second choice was also about the last seconds in the green interval, but this time it was about safety. Of the participants, 58% decided to stop and wait for the next green interval to cross due to a concise time displayed time which they thought might not be sufficient to cross the road. Some participants (14%) indicated they went faster while crossing. This might lead to having more successful crossings. Only 3% chose to move slower.

The conclusion from this question could be that PCTs can increase safety for pedestrians by helping in decision-making when to cross or stop, or how to change walking speed based on the remaining time. Also, it can be concluded that PCTs can increase the possibility of successful crossings by changing crossing behaviour. The results of this question are illustrated in **Figure 26**.

Table 34: Participant opinion regarding pedestrian green countdown timer

Question	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Don't know
Changing walking speed	44%	45%	8%	1%	0%	2%

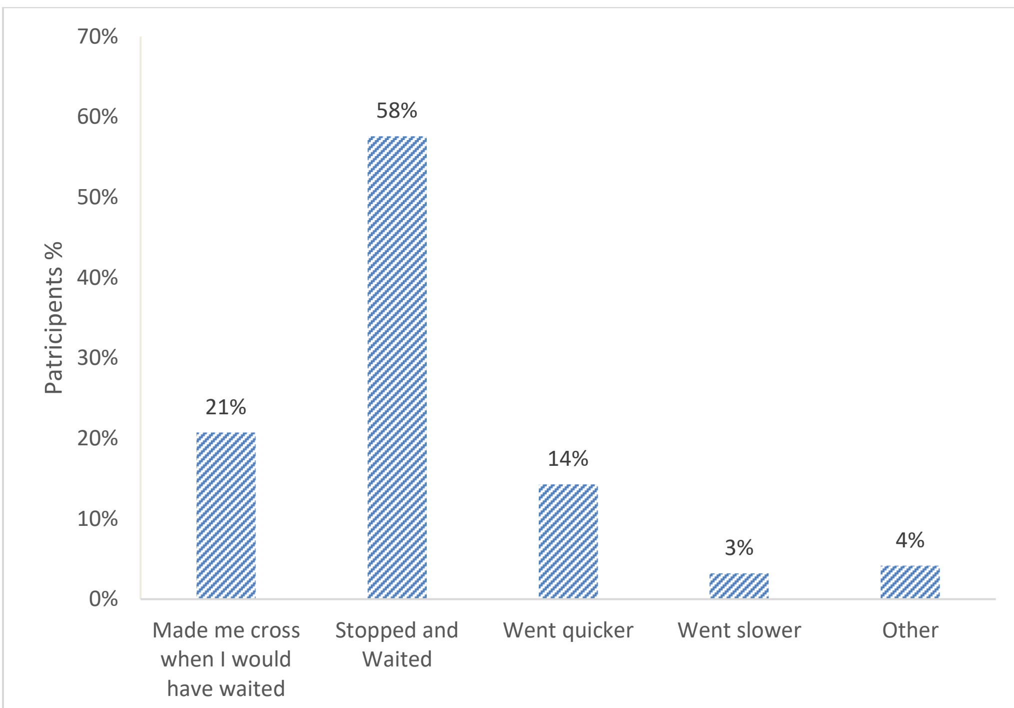


Figure 26: Perception of change in the behaviour of pedestrians at sites with countdown signals

4.3.3. Inferential statistics

In this section, the results are analysed after categorising survey responses based on the demographic and general question answers from participants. The whole survey has been divided into five categories (residential status, gender, age group, number of trips, and familiarity).

Residential status

Emiratis were only 5% of the total participants. None of them indicated they crossed every day. More than 80% of them were educated as an undergraduate or more. **Table 35** shows the demographic characteristics of Emirati participants. Of those, 80% preferred the PCT to be installed at the crossing, and they thought that the crossing could be safer with PCTs by reducing red-light violations. More than 75% of them agreed that PCTs could relieve frustration during the waiting time and improve walking speed during the crossing.

Table 35: Emirati participant PCT survey results

Gender		Age		Education Level		Familiar		Cross/Week	
Male	52%	**18-24**	24%	**High School**	16%	**yes**	96%	**<1**	48%
Female	48%	**25-34**	20%	**Under Graduate**	68%	**no**	4%	**1-3**	52%
		35-44	48%	**Post Graduate**	16%			**4-6**	0%
		45-54	8%					**>6**	0%
		55	0%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	32%	28%	20%	24%	16%
Agree	48%	60%	64%	52%	68%
Neutral	12%	4%	4%	8%	8%
Don't agree	0%	0%	4%	0%	4%
Str disagree	4%	4%	4%	4%	0%
Don't know	4%	4%	4%	12%	4%

The non-Emirati residents were the vast majority of participants (95%). Around 40% of them were using the pedestrian crossing at least four times per week. Of those, 97% were familiar with PCTs, and most of them were well educated. **Table 36** shows the survey results of residents participating in the survey. Almost 90% of them preferred the PCT at the pedestrian crossing, thinking that it can increase safety. More than 80% of them thought that it could prevent red-light violations and relieve frustration during the waiting time. Almost 90% of them thought that it could guide them to change walking speed based on the remaining time shown.

Table 36: Resident participant PCT survey results

Gender		Age		Education Level		Familiar		Cross/Week	
Male	60%	**18-24**	38%	**High School**	10%	**Yes**	97%	**<1**	19%
Female	40%	**25-34**	29%	**Under Graduate**	69%	**No**	3%	**1-3**	32%
		35-44	17%	**Post Graduate**	21%			**4-6**	22%
		45-54	11%					**>6**	27%
		55	5%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	52%	51%	41%	39%	45%
Agree	36%	38%	40%	41%	44%
Neutral	9%	8%	12%	14%	8%
Don't agree	1%	1%	4%	3%	1%
Str disagree	1%	0%	2%	1%	0%
Don't know	1%	1%	1%	2%	1%

In comparison between Emiratis and non-Emiratis, there was a significant difference in three questions: the general question about the safety, the question related to frustration, and the question about walking speed change. In general, residents were more positive than the Emiratis. The reason could be because the residents more frequently used the crossings, which makes them give more positive answers.

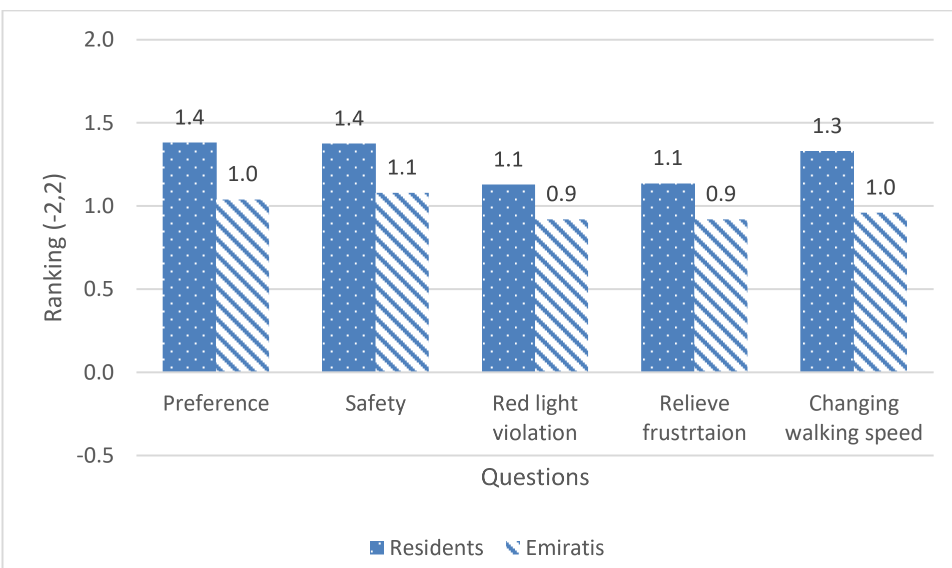


Figure 27: Comparison between Emirati and resident participants' opinions regarding PCT

Gender

Table 37 and **Table 38** shows the demographic characteristics of male and females participants. Most of the participants, either males or females, preferred PCTs. They thought that PCTs could make the crossing safer. Around 80% of them agreed that PCTs could prevent red-light violations and relieve frustration while stopping during the red interval. Regarding the last question, they also thought that PCTs could provide a correct indication of the remaining time so that they can change their walking speed accordingly. There was no significant difference between all the questions between male and female respondents.

Table 37: Male participant PCT survey results

Resident Status		Age		Education Level		Familiar		Cross/Week	
Emirati	4%	**18-24**	35%	**High School**	10%	**Yes**	97%	**<1**	18%
Resident	95%	**25-34**	28%	**Under Graduate**	65%	**No**	3%	**1-3**	35%
Tourist	1%	**35-44**	21%	**Post Graduate**	24%			**4-6**	18%
		45-54	10%					**>6**	30%
		55	6%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	56%	50%	40%	41%	46%
Agree	33%	37%	39%	40%	41%
Neutral	9%	9%	13%	12%	10%
Don't agree	1%	2%	4%	4%	1%
Str disagree	1%	1%	2%	1%	1%
Don't know	1%	1%	2%	3%	1%

Table 38: Female participant PCT survey results

Resident Status		Age		Education Level		Familiar		Cross/Week	
Emirati	6%	**18-24**	40%	**High School**	10%	**Yes**	98%	**<1**	24%
Resident	93%	**25-34**	29%	**Under Graduate**	74%	**No**	3%	**1-3**	32%
Tourist	1%	**35-44**	16%	**Post Graduate**	16%			**4-6**	25%
		45-54	13%					**>6**	20%
		55	3%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	45%	50%	39%	34%	41%
Agree	42%	42%	44%	46%	51%
Neutral	10%	6%	10%	17%	6%
Don't agree	1%	0%	4%	2%	1%
Str disagree	1%	1%	2%	1%	0%
Don't know	3%	2%	1%	2%	2%

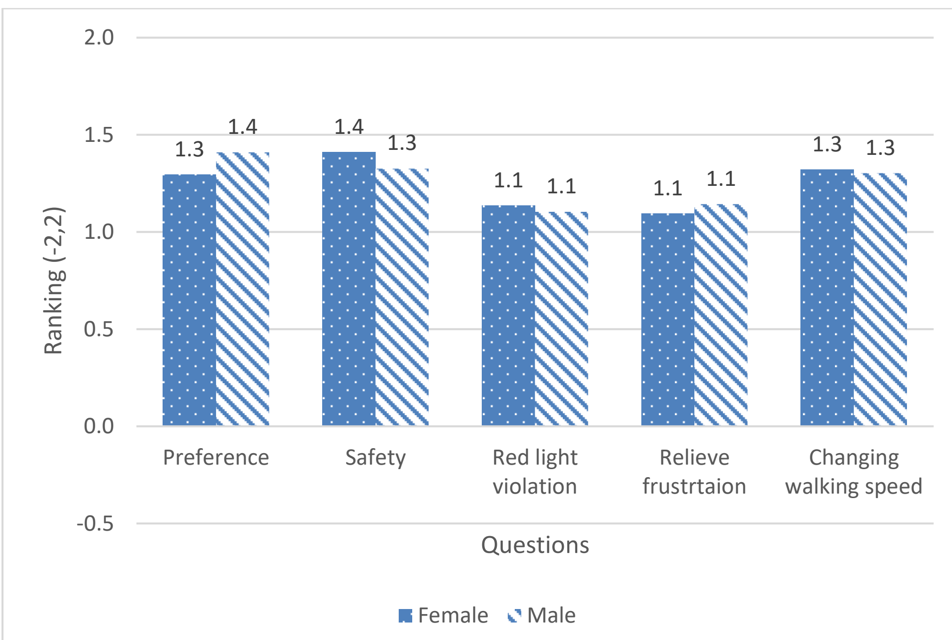


Figure 28: Comparison between male and female participants' opinions regarding PCT

Age group distribution

Table 39 shows the demographic characteristics of the groups aged between 18 to 24. More than 80% of them used the crossing at least once a week. More than 95% of the participants were aware of the PCT, as well as the other age groups as shown in **Table 40**, **Table 41,** and **Table 42**. On average, 80% of them agreed to all questions. The least agreement was found in question was the third question regarding red-light violation prevention.

Table 39: 18-24 years old participant PCT survey results

Resident Status		Gender		Education Level		Familiar		Cross/Week	
Emirati	3%	**Male**	57%	**High School**	10%	**Yes**	98%	**<1**	19%
Resident	97%	**Female**	43%	**Under Graduate**	84%	**No**	2%	**1-3**	38%
Tourist	0%			**Post Graduate**	6%			**4-6**	18%
								>6	24%

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	46%	42%	35%	38%	40%
Agree	37%	40%	41%	41%	45%
Neutral	14%	14%	16%	17%	11%
Don't agree	2%	2%	5%	2%	1%
Str disagree	1%	1%	1%	1%	1%
Don't know	1%	2%	1%	3%	3%

The second age group included participants between 25 to 34 years old (**Table 40**). In comparison with the previous age group, there was only a significant difference in question number two, which was about increasing safety. This group was more positive toward this question.

Table 40: 25-34 years old participant PCT survey results

Resident Status		Gender		Education Level		Familiar		Cross/Week	
Emirati	4%	**Male**	59%	**High School**	8%	**Yes**	96%	**<1**	20%
Resident	96%	**Female**	41%	**Under Graduate**	61%	**No**	4%	**1-3**	33%
Tourist	1%			**Post Graduate**	31%			**4-6**	18%
								>6	30%

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	52%	52%	38%	31%	41%
Agree	38%	42%	42%	49%	46%
Neutral	6%	5%	11%	13%	10%
Don't agree	0%	0%	4%	4%	1%
Str disagree	1%	1%	3%	0%	0%
Don't know	1%	1%	3%	4%	1%

Table 41 shows the demographic characteristics of the age group 35-44 years old. It has almost the same characteristics of previous age groups. The trips are well distributed, and 85% of respondents were at least undergraduates. In comparison to the youngest group, there was no significant difference between all the questions. However, with comparison with the previous age group, there was a significant difference in question four about relieving frustration. This group was more positive than others.

Table 41: 35-44 years old participant PCT survey results

Resident Status		Gender		Education Level		Familiar		Cross/Week	
Emirati	13%	**Male**	66%	**High School**	15%	**Yes**	97%	**<1**	21%
Resident	87%	**Female**	34%	**Under Graduate**	54%	**No**	3%	**1-3**	24%
Tourist	0%			**Post Graduate**	31%			**4-6**	29%
								>6	26%

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	53%	55%	48%	46%	49%
Agree	35%	35%	36%	37%	44%
Neutral	7%	4%	10%	9%	5%
Don't agree	1%	3%	3%	4%	1%
Str disagree	1%	1%	2%	3%	1%
Don't know	2%	1%	1%	1%	0%

The oldest age group of participants was 45 years and above. **Table 42** shows the demographic characteristics of this group. There was no significant difference between this group and all other groups. In general, this group was the most positive group. It is noticeable that this older group provided more positive opinions, as shown in **Figure 29**.

Table 42: 45+ years old participant PCT survey results

Resident Status		Gender		Education Level		Familiar		Cross/Week	
Emirati	4%	**Male**	55%	**High School**	13%	**Yes**	100%	**<1**	16%
Resident	96%	**Female**	45%	**Under Graduate**	64%	**No**	0%	**1-3**	32%
Tourist	0%			**Post Graduate**	24%			**4-6**	29%
								>6	23%

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	63%	61%	43%	43%	54%
Agree	30%	36%	43%	38%	43%
Neutral	4%	2%	7%	13%	2%
Don't agree	0%	0%	0%	5%	0%
Str disagree	0%	0%	5%	0%	0%
Don't know	4%	2%	2%	2%	2%

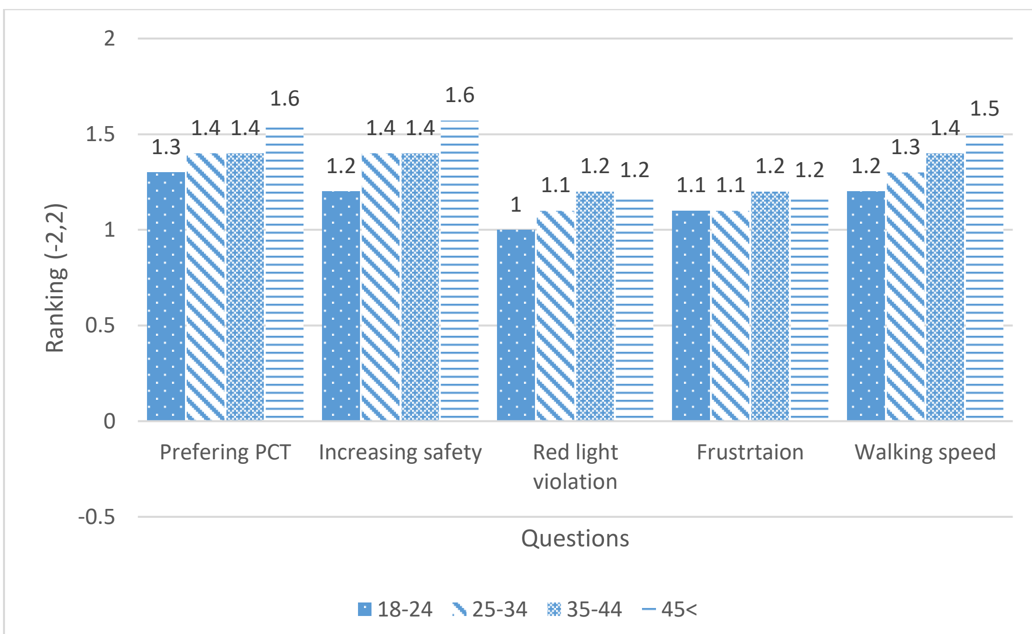


Figure 29: Comparison between age groups participants opinion scaling regarding PCT

Number of crossings per day

The first group of participants was using the intersection to cross the road less than once a week. **Table 43** shows the demographic characteristics of this group. Even though they had the least time crossing, 95%

of them were familiar with PCTs. They were positive toward questions two and five, whereas they were less positive toward questions three and four.

Table 43: Participants with less than one crossing/week PCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	12%	**18-24**	36%	**High School**	8%	**Male**	53%	**Yes**	95%
Resident	88%	**25-34**	28%	**Under Graduate**	77%	**Female**	47%	**No**	5%
Tourist	0%	**35-44**	20%	**Post Graduate**	15%				
		45-54	9%						
		55	7%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	43%	49%	40%	34%	40%
Agree	39%	35%	37%	38%	48%
Neutral	11%	12%	10%	23%	9%
Don't agree	0%	1%	4%	1%	1%
Str disagree	2%	1%	6%	1%	0%
Don't know	5%	2%	3%	3%	2%

The second group of participants were crossing 1-3 times/week. The results of their answers are shown in **Table 44**. There was a significant difference in question number three in the comparison between this group and the previous group. This group was more favourable toward the PCT.

Table 44: Participants with 1-3 crossings/week PCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	8%	**18-24**	42%	**High School**	14%	**Male**	62%	**Yes**	98%
Resident	90%	**25-34**	28%	**Under Graduate**	69%	**Female**	38%	**No**	2%
Tourist	2%	**35-44**	14%	**Post Graduate**	17%				
		45-54	11%						
		55	6%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	45%	41%	33%	31%	35%
Agree	41%	49%	50%	47%	54%
Neutral	11%	7%	11%	11%	8%
Don't agree	1%	2%	4%	6%	0%
Str disagree	1%	1%	1%	2%	1%
Don't know	1%	1%	1%	3%	2%

The participants with 4-6 crossings/week were also familiar with PCTs (97%), as shown in **Table 45**. More than 90% of them preferred to use intersections with a PCT. Of the respondents, 87% thought that PCTs could provide a safer crossing environment. In a comparison between this group and previous groups, there was no significant difference in all questions.

Table 45: Participants with 4-6 crossings/week PCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	0%	**18-24**	33%	**High School**	8%	**Male**	51%	**Yes**	97%
Resident	99%	**25-34**	24%	**Under Graduate**	65%	**Female**	49%	**No**	3%
Tourist	1%	**35-44**	26%	**Post Graduate**	27%				
		45-54	16%						
		55	1%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	53%	53%	39%	40%	49%
Agree	38%	34%	38%	46%	39%
Neutral	6%	9%	15%	12%	10%
Don't agree	1%	1%	5%	1%	1%
Str disagree	0%	0%	2%	0%	0%
Don't know	2%	3%	1%	2%	2%

In the group with six crossings/week, 99% of the participants were familiar with PCTs (**Table 46**). This is a logical result as they are crossing the road almost every day. Of those, 70% were male, and more than 90% of them were well educated. None of them was Emirati. They were the most positive group, as shown in **Figure 30**. In a comparison between this group and the first group, there was only a significant difference in the first question. This group was more favourable toward PCTs at pedestrian crossings. Comparing with the second group, there was a significant difference in the three questions which were the first, second, and last question. Again, this group was more positive. There was no difference between this group and the previous group. It can be noticed that as pedestrians use an intersection with a PCT more frequently, they become more positive toward PCTs and their benefits, as shown in **Figure 30**.

Table 46: Participants with at least six crossings/week PCT survey results

Residents		Age		Education Level		Gender		Familiar	
Local	0%	**18-24**	35%	**High School**	9%	**Male**	69%	**Yes**	99%
Resident	99%	**25-34**	32%	**Under Graduate**	66%	**Female**	31%	**No**	1%
Tourist	1%	**35-44**	18%	**Post Graduate**	25%				
		45-54	10%						
		55	5%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	64%	59%	48%	48%	55%
Agree	27%	34%	35%	36%	36%
Neutral	8%	5%	12%	11%	8%
Don't agree	1%	2%	4%	3%	2%
Str disagree	1%	1%	2%	1%	0%
Don't know	0%	0%	1%	2%	0%

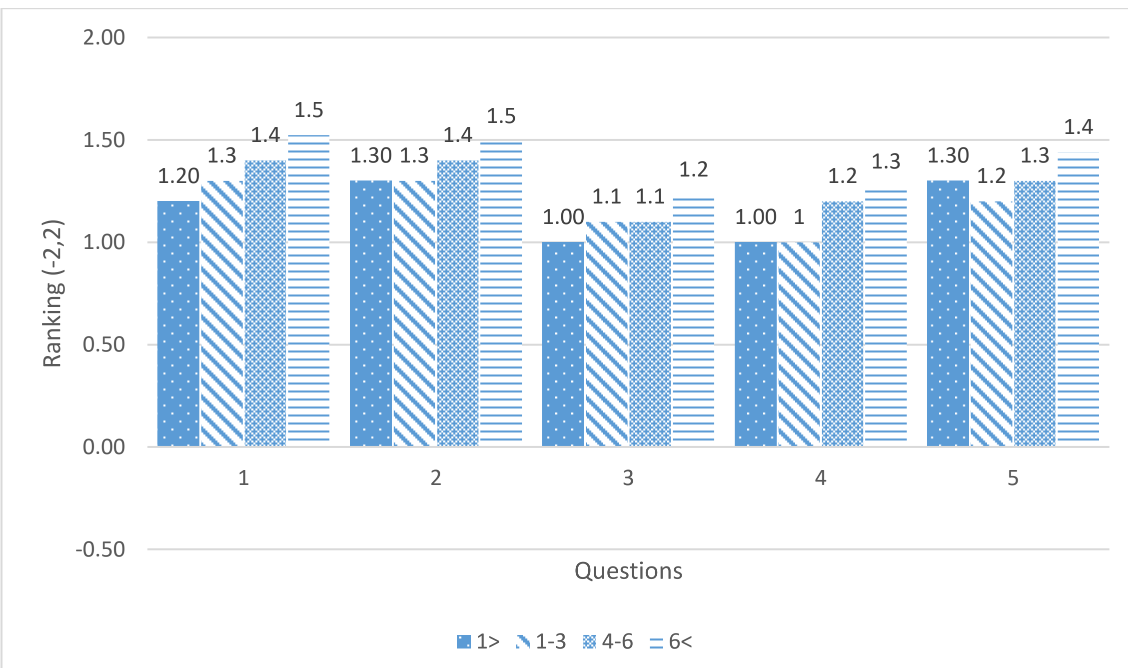


Figure 30: Comparison between participants with different pedestrian crossing trips/week

Educational level

The educational level has been divided into three categories: high school diploma and below, undergraduate, and postgraduate. The participants from the first category were 100% familiar with PCTs. In that group, 84% of them were crossing the road at least once/week, as shown in

Table 47, and 88% of them preferred to use the PCT mainly because of safety issues. The question that they were not very confident about was the question related to relieving frustration. In this group, 26% of them did not show a definite answer (don't know and neutral). Overall, 68% of them agreed, and 6% did not agree.

Table 47: Participants with high school education and below PCT survey results

Residents		Age		Familiar		Gender		Crossing/Week	
Local	8%	**18-24**	35%	**Yes**	100%	**Male**	61%	**1**	16%
Resident	90%	**25-34**	22%	**No**	0%	**Female**	39%	**1-2**	45%
Tourist	2%	**35-44**	27%					**3-4**	16%
		45-54	14%					**4-5**	24%
		55	2%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	55%	51%	39%	31%	35%
Agree	33%	39%	53%	37%	51%
Neutral	8%	6%	6%	18%	6%
Don't agree	0%	0%	0%	6%	2%
Str disagree	0%	0%	0%	0%	0%
Don't know	4%	4%	2%	8%	6%

Table 48 shows demographic characteristics of participants with undergraduate educational level their opinions about PCTs. They were confident regarding all questions. In the comparison between this group and the previous group, there was no significant difference in all questions.

Table 48: Participants with undergraduate education PCT survey results

Residents		Age		Familiar		Gender		Car Trips/Day	
Local	5%	**18-24**	46%	**Yes**	97%	**Male**	57%	**1**	23%
Resident	94%	**25-34**	25%	**No**	3%	**Female**	43%	**1-2**	33%
Tourist	1%	**35-44**	15%					**3-4**	20%
		45-54	10%					**4-5**	25%
		55	5%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	49%	49%	39%	37%	43%
Agree	38%	39%	41%	44%	46%
Neutral	9%	9%	11%	14%	9%
Don't agree	1%	1%	5%	2%	0%
Str disagree	1%	1%	2%	1%	0%
Don't know	1%	1%	1%	2%	1%

Participants in the most educated group were also familiar with PCTs and confident in their opinions. Almost 90% of them preferred PCTs and thought that they increased safety and reduced red-light violations. **Table 49** shows the results related to this group. In a comparison between all educational groups, there was no significant difference between all of them in all questions. **Figure 31** illustrates the results of different educational group answers.

Table 49: Participants with postgraduate education PCT survey results

Residents		Age		Familiar		Gender		Car Trips/Day	
Local	4%	**18-24**	10%	**Yes**	97%	**Male**	70%	**1**	14%
Resident	94%	**25-34**	42%	**No**	3%	**Female**	30%	**1-2**	28%
Tourist	2%	**35-44**	28%					**3-4**	26%
		45-54	13%					**4-5**	32%
		55	7%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	56%	52%	40%	43%	50%
Agree	33%	37%	36%	39%	38%
Neutral	9%	6%	16%	10%	8%
Don't agree	0%	2%	3%	6%	2%
Str disagree	1%	1%	4%	1%	1%
Don't know	1%	2%	1%	1%	0%

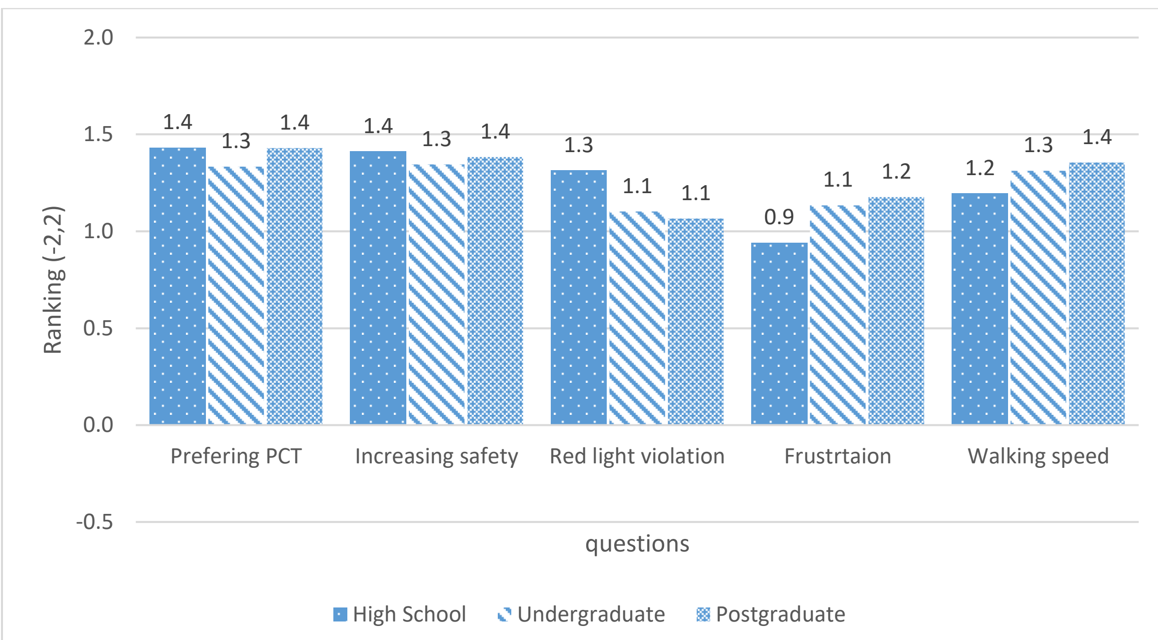


Figure 31: Comparison between different educational levels of participants regarding PCT

Familiarity

In the pedestrian survey, out of 500 participants, there were only 13 participants who were not familiar with PCTs. **Table 50** and **Table 51** are the demographic characteristics and results of the questionnaire for both familiar and non-familiar participants with PCT. The comparison of these two categories had a significant difference in the third question about the red-light violations. Participants who were familiar with PCT systems were more confident and transparent in their opinions, as shown in **Figure 32**.

Table 50: Participant survey results who were familiar with PCTs

Residents		Age		Education Level		Gender		Car Trips/Day	
Local	5%	**18-24**	37%	**High School**	11%	**Male**	60%	**1**	20%
Resident	94%	**25-34**	28%	**Under Graduate**	69%	**Female**	40%	**1-2**	33%
Tourist	1%	**35-44**	19%	**Post Graduate**	21%			**3-4**	21%
		45-54	11%					**4-5**	26%
		55	5%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	52%	51%	40%	38%	44%
Agree	36%	39%	41%	42%	44%
Neutral	9%	8%	12%	14%	8%
Don't agree	1%	1%	4%	3%	1%
Str disagree	1%	1%	2%	1%	0%
Don't know	2%	1%	1%	2%	2%

Table 51: Participant survey results who were not familiar with PCTs

Residents		Age		Education Level		Gender		Car Trips/Day	
Local	8%	**18-24**	31%	**High School**	8%	**Male**	62%	**1**	31%
Resident	92%	**25-34**	46%	**Under Graduate**	92%	**Female**	38%	**1-2**	46%
Tourist	0%	**35-44**	23%	**Post Graduate**	0%			**3-4**	23%
		45-54	0%					**4-5**	0%
		55	0%						

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	31%	23%	23%	31%	23%
Agree	54%	54%	46%	38%	69%
Neutral	8%	8%	0%	15%	8%
Don't agree	8%	8%	15%	8%	0%
Str disagree	0%	0%	0%	0%	0%
Don't know	0%	8%	15%	8%	0%

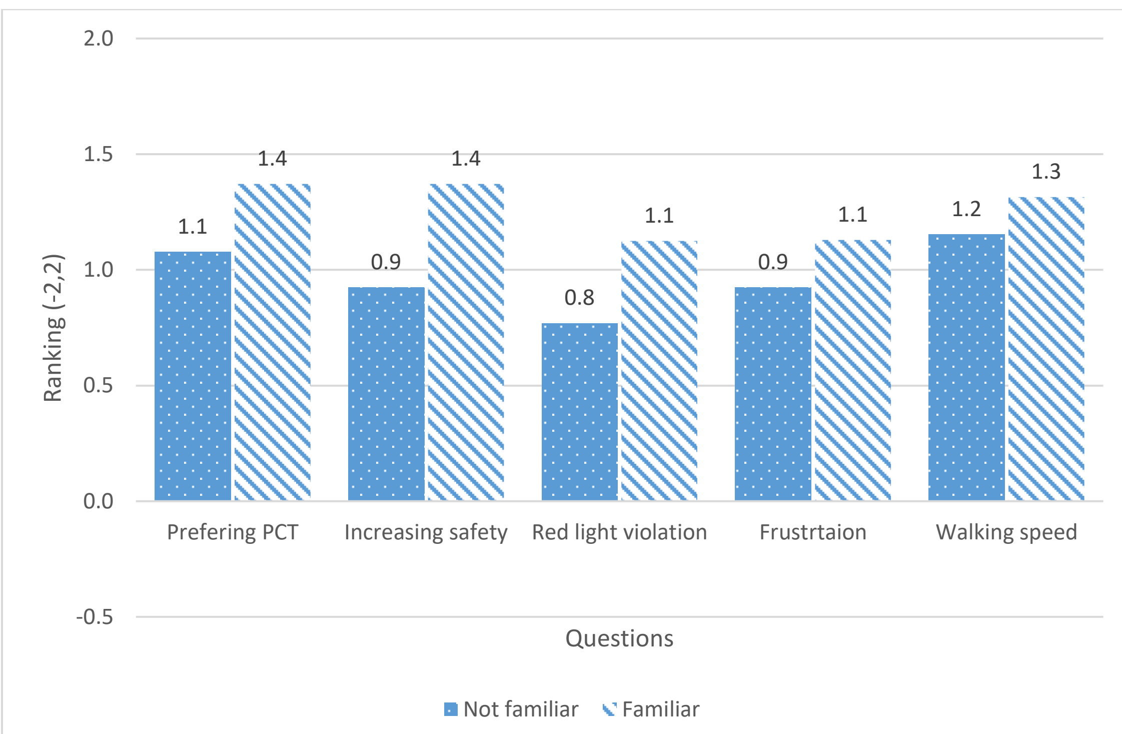


Figure 32: Comparison between participants who were familiar and not familiar with PCTs

Treatment and control sites

Table 52 and **Table 53** are the demographic characteristics and results of the questionnaire for both control and treatment site participants. The comparison of these two categories had no significant difference in all questions. Participants who were familiar with PCT systems were more confident and clear in their opinions, as shown in **Figure 32**.

Table 52: Participant PCT survey results from the control site

Residents		Age		Education Level		Gender		Crossing /week		Familiar	
Local	6%	**18-24**	34%	**High School**	11%	**Male**	60%	**1**	17%	**yes**	100%
Resident	92%	**25-34**	30%	**Undergraduate**	69%	**Female**	40%	**1-2**	33%	**No**	0%
Tourist	2%	**35-44**	18%	**Postgraduate**	20%			**3-4**	18%		
		45-54	12%					**4-5**	32%		
		55	6%								

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	52%	51%	40%	38%	44%
Agree	36%	39%	41%	42%	44%
Neutral	9%	8%	12%	14%	8%
Don't agree	1%	1%	4%	3%	1%
Str disagree	1%	1%	2%	1%	0%
Don't know	2%	1%	1%	2%	2%

Table 53: Participant PCT survey results from the treatment site

Residents		Age		Education Level		Gender		Crossing /w		Familiar	
Local	4%	**18-24**	34%	**High School**	11%	**Male**	60%	**1**	17%	**Yes**	100%
Resident	96%	**25-34**	30%	**Undergraduate**	69%	**Female**	40%	**1-2**	33%	**No**	0%
Tourist	0%	**35-44**	18%	**Postgraduate**	20%			**3-4**	18%		
		45-54	12%					**4-5**	32%		
		55	6%								

Questions rating	Preferring PCT	Increase safety	Violation	Frustration	Walking speed
Strongly agree	31%	23%	23%	31%	23%
Agree	54%	54%	46%	38%	69%
Neutral	8%	8%	0%	15%	8%
Don't agree	8%	8%	15%	8%	0%
Str disagree	0%	0%	0%	0%	0%
Don't know	0%	8%	15%	8%	0%

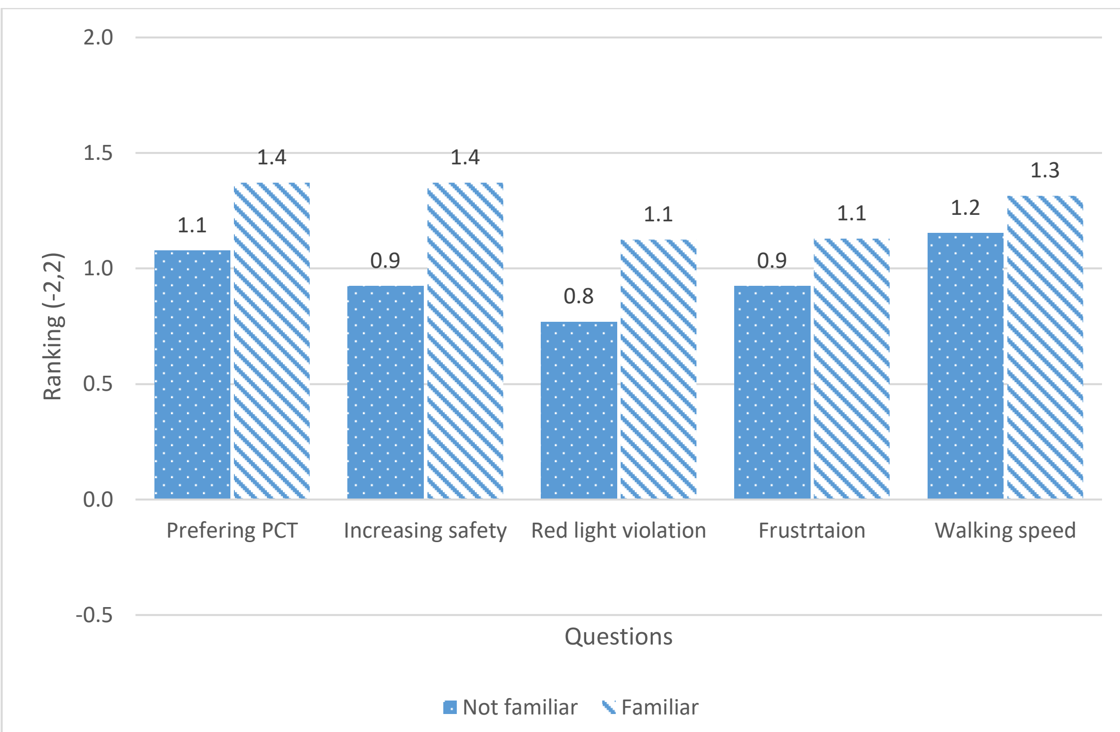


Figure 33: Comparison between participants who were familiar and not familiar with PCTs

4.4. Summary and conclusion

Determining user perception is a significant mechanism that transportation designers can use to evaluate any traffic control device before installation. A standard way to determine user perception before installing a new system or device is to conduct studies of user preferences or opinions. This study used survey questionnaires to assess public perception of signal countdown timers in UAE. Two questionnaires were prepared, one to assess the perception of drivers toward vehicle countdown timers and one to assess the perception of pedestrians toward pedestrian countdown timers. Both types of SCTs are used at various places in UAE.

A total of 1,000 valid questionnaires were collected in May 2015. Of those, 500 were answered by drivers and 500 by pedestrians. About 200 questionnaires were collected at different places in different cities for drivers, and 272 questionnaires were collected directly from pedestrians crossing intersections. The remaining 300 questionnaires for the drivers and 228 for the pedestrians were collected online.

4.4.1. Driver Perception

The driver questionnaire included three sections. The first section covered demographic and general questions. The second section contained questions related to red interval countdown timers. The third section asked questions related to green countdown timers.

Questions regarding red countdown timers focused on driver perception as to whether the timers would enable drivers to: experience less frustration from stopping for long and uncertain amounts of time; make better use of waiting time during a red light; turn off the car's engine while waiting in the queue (to achieve economic and environmental benefits); and proceed promptly through the intersection when the signal turned green.

Questions regarding driver perception of green countdown timers asked if drivers felt the timers would: assist them in better judging when to stop for a signal turning from green to red; and ensure confidence in driving thru an intersection during a green light.

To best assess public perception regarding countdown timers, several demographic questions were asked in each survey. The first question asked the zone or emirate of residence because each emirate has slightly different characteristics of traffic control. The second question asked about resident status: "Resident" identified a person living in UAE as a resident but not Emirati; "Local" identified Emiratis; "Tourist" identified visitors. The third question asked about gender. The fourth question was about age, divided into five groups. The age groups started at 18 years because that is the age of getting a driving license in UAE. The first age group was between 18 to 24, and subsequent age groups were divided every ten years. The fifth question was about educational level, divided into four categories: participants who had a high school degree and below; participants with undergraduate degrees; participants with master's degrees; and participants with doctoral degrees.

The sixth question asked whether the participant had an opinion about vehicle countdown timers. This question was asked because most of the surveys were conducted in Sharjah, where there are no VCTs installed yet. To make sure that the participant understood the question, a brief description about VCTs was given. The last question was about how many daily cars trips the participant made. This question was asked to discover any differences between expert and non-expert drivers' answers.

Overall, most of the drivers thought that red countdown timers had a positive impact. More than 80% of the drivers thought that a red countdown timer could relieve frustration from stopping for long, unknown periods of time during the red interval, especially when a signal has long cycle times. About 71% of the drivers thought that the timer could result in better use of their waiting time during the red interval, and 85% of the drivers indicated that it could assist them to proceed through the intersection when the signal turned green promptly.

Most drivers also felt that green countdown timers had a positive impact. About 87% of the drivers thought positively about green countdown timers. Statistical comparison with the 79% of drivers who thought positively about red countdown timers indicates there is no significant difference between the perception of drivers toward red and green countdown timers.

Significant differences were found between groups in each demographic category. This chapter details the findings of each demographic group to show differences and similarities in the perception of signal countdown timers. A common thread running throughout most groups reflects resistance to turning off the car engine while waiting for a red light, even with a red signal countdown timer in place.

4.4.2. Pedestrian Perception

The pedestrian survey focused on pedestrians' comprehension and preferences toward PCTs in the UAE. It was designed to gain an overall idea of pedestrians' opinions of countdown signals regarding preference, safety, compliance, comfort level, speed, and crossing behaviour.

The questionnaire was divided into four sections plus an open-ended comment box. The first section asked the same demographic and general questions as those in the driver survey. The second section asked two general questions about pedestrian countdown timers. The third section asked about red countdown timers, and the fourth section asked about green countdown timers.

The first general question asked was whether pedestrians preferred PCTs at pedestrian crossings. Most respondents (87%) agreed and recommended the installation of PCTs.

About 80% of the pedestrians thought positively about red countdown timers. Regarding red countdown timers, about 80% of pedestrians thought that the timers could prevent them from crossing during a red interval since they would know the remaining time. Moreover, 80% thought that the red countdown timer could relieve their frustration from stopping for an extended and unknown amount of time.

Nearly 89% of pedestrians thought positively about green countdown timers. Regarding green countdown timers, the vast majority of pedestrians surveyed (about 89%) agreed that the timers could help them make a better judgment whether to move faster or slower while crossing, or whether to attempt a crossing at all. **Table 54** and **Table 55** shows the Chi-Square test results for both questionnaires.

Table 54: Chi-Square test results for drivers about the vehicle countdown timers

Significant difference between		Q1	Q2	Q3	Q4	Q5	Q6
Local	**Resident**	No	Yes	Yes	Yes	Yes	Yes
Male	**Female**	No	No	Yes	Yes	Yes	No
18-24	**25-34**	No	No	No	No	Yes	Yes
18-24	**35-44**	Yes	Yes	Yes	Yes	Yes	Yes
18-24	**45-54**	Yes	Yes	Yes	Yes	Yes	Yes
25-34	**35-44**	No	No	Yes	No	No	No
25-34	**45-54**	Yes	Yes	No	Yes	No	No
35-44	**45-54**	No	No	Yes	No	No	No
<1 trip	**1-2 Trips**	No	No	No	No	No	No
<1 trip	**3-4 Trips**	No	No	Yes	No	No	No
<1 trip	**>4 Trips**	No	Yes	No	No	Yes	No
1-2 Trips	**3-4 Trips**	No	No	No	No	No	No
1-2 Trips	**>4 Trips**	Yes	Yes	No	Yes	Yes	No
3-4 Trips	**>4 Trips**	No	Yes	Yes	Yes	No	No
H. school	**Under G**	No	Yes	Yes	No	No	No
H. school	**Post G**	No	No	No	No	No	No
Under G	**Post G**	No	No	No	No	No	No
Familiar	**Not Familiar**	Yes	Yes	No	Yes	Yes	Yes

Table 55: Chi-Square test results for pedestrians about the pedestrian countdown timers

Significant difference between		Q1	Q2	Q3	Q4	Q5
Local	**Resident**	No	Yes	No	Yes	Yes
Male	**Female**	No	No	No	No	No
18-24	**25-34**	No	Yes	No	No	No
18-24	**35-44**	No	No	No	No	No
18-24	**45-54**	No	No	No	No	No
25-34	**35-44**	No	No	No	Yes	No
25-34	**45-54**	No	No	No	No	No
35-44	**45-54**	No	No	No	No	No
<1 trip	**1-3 Trips**	No	No	Yes	No	No
<1 trip	**4-6 Trips**	No	No	No	No	No
<1 trip	**>6 Trips**	Yes	No	No	No	No
1-3 Trips	**4-6 Trips**	No	No	No	No	No
1-3 Trips	**>6 Trips**	Yes	Yes	No	No	No
4-6 Trips	**>6 Trips**	No	No	No	No	No
H. school	**Under G**	No	No	No	No	No
H. school	**Post G**	No	No	No	No	No
Under G	**Post G**	No	No	No	No	No
Familiar	**Not Familiar**	No	No	Yes	No	No

From **Table 54** and **Table 55** it can be noticed that there are more significant differences between drivers opinion than the pedestrians.

5. Countdown timer algorithm development and testing

This chapter describes the algorithm designed to develop a prediction method and change the speed of countdown timers to suit the phase duration for traffic signals in actuated mode. The algorithm was tested under a simulation environment using microsimulation software VISSIM, and the results from the simulation were evaluated to check the algorithm's performance. Red time interval prediction method was proposed for signals running under actuated mode to evaluate the performance of the countdown timer algorithm. The outcomes described in this chapter were used as a real sample for the analyses and evaluation of the algorithm discussed in the next chapter.

5.1. Simulation environment

In this study, a signalised intersection in Sharjah City was chosen as a case study. Around 70% of all signal-controlled intersections in Sharjah City use the same logic as the case study intersection. **Figure 36** and **Figure 37** show the location and aerial photo of the intersection where **Figure 38** shows the layout and loop detector location. The intersection has four approaches, and each approach is operated as an individual phase as shown in **Figure 34**. Since the left turns are protected, four phases are running in strict order. The logic does not have any phase skipping or public transport priority system. Each approach has a minimum and maximum green time. Minimum green is extended up to maximum green as long as the headways at the stop line detector do not exceed a time threshold (2.5s). Traffic volume counts have been carried on the third of Feb 2015 between 6 AM and 11 PM. **Figure 35** shows the result of the traffic counts for each approach at the junction.

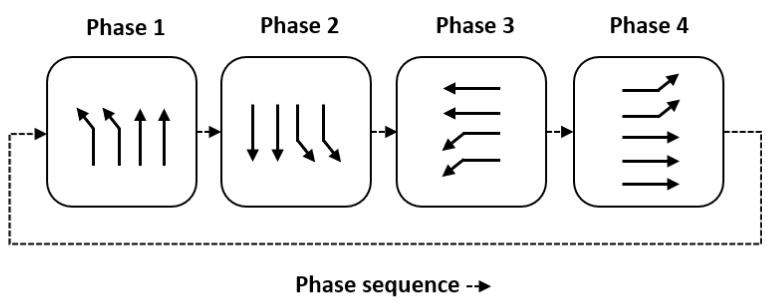


Figure 34: Phase diagram for Al Nakhi junction

Usually, up to five parameter sets are available for different traffic flow levels by time of day. Approach one (Eastbound) is a major approach linked to another signalised junction. Approach two (Westbound) is a major approach where the traffic is approaching in free flow. The third approach (Northbound) is a minor approach coming from Ajman City. The last approach (Southbound) is a minor approach coming from the city centre. The Southbound approach has been chosen to be the minor approach for the case study. Using a traffic flow simulation model, VISSIM, the traffic signal logic was programmed to project the real traffic situation.

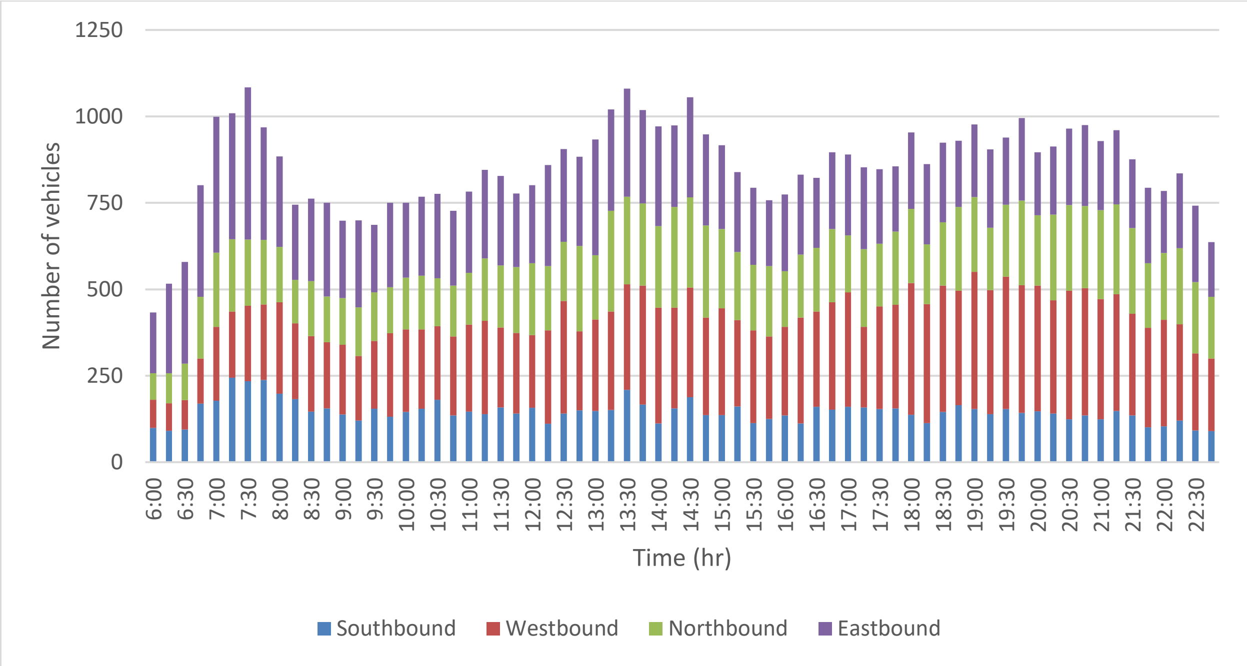


Figure 35: Traffic volume at Al Nakhi junction 3rd of Feb 2015

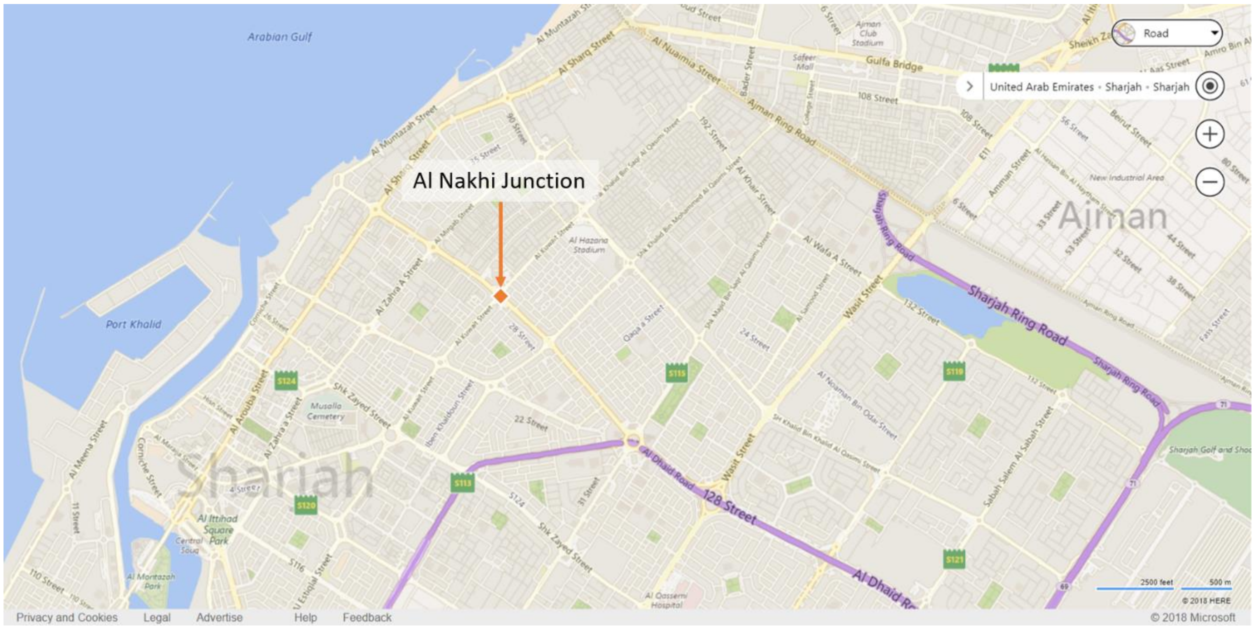


Figure 36: Al Nakhi junction location map

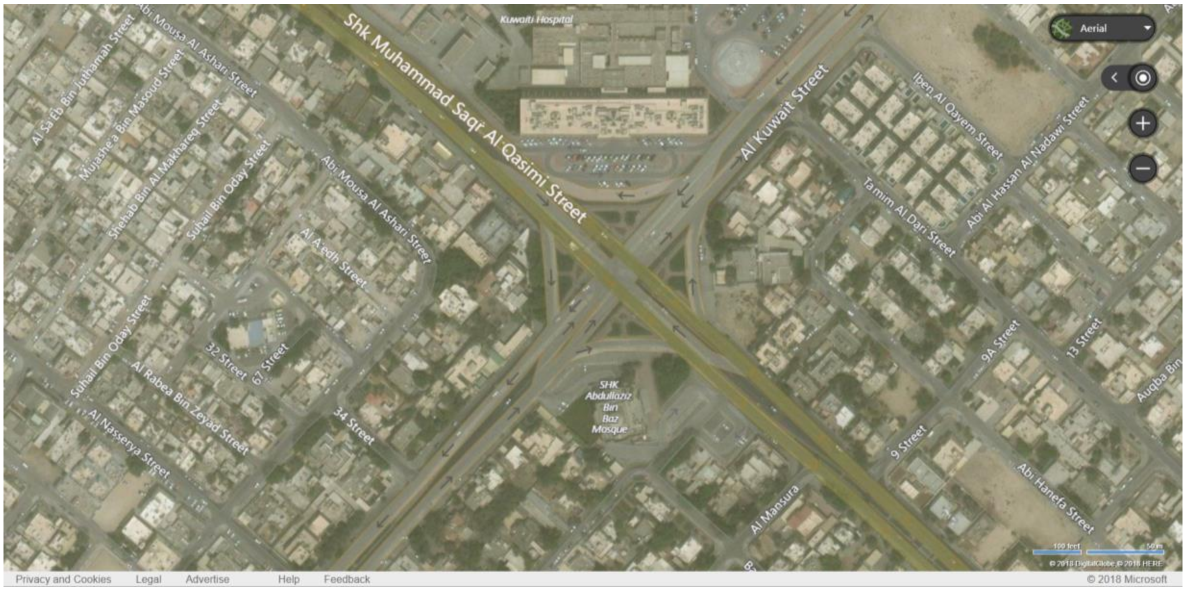


Figure 37: Arial map showing the layout of Al Nakhi junction

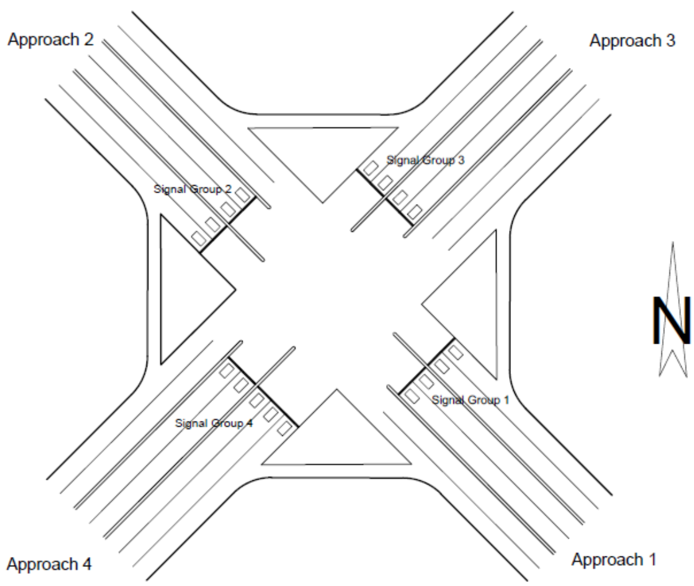


Figure 38: Actuated signalised junction layout

5.2. VCT red time prediction

5.2.1. Short-term prediction methods

The short-term traffic forecasting has been a vital consideration in different fields of transportation research over the last three decades. This interest has piqued for creating user-friendly applications that can be utilised for signal optimisation, intelligent traffic control methods and advanced passenger information applications and systems. Being a fundamental part of the Intelligent Transportation System, short-term traffic forecasting mostly relates to developing methodologies which can be used firstly to model the traffic characteristics followed by producing anticipated traffic conditions. It aims to predict the future criterions such as travel time in parts of the road network in urban areas, speed, density or traffic volume (Kubek, Więcek and Chwastek, 2016). The time horizon in this prediction stretches from just a couple of seconds to the utmost of a few hours. Based on the historical and the current traffic information the values will be evaluated. The focus of this study was on the prediction of the traffic signal's upcoming interval time.

Predicting the future state of an actuated traffic signal can be challenging due to much uncertainty in its timing and phase. On the other hand, things are more straightforward in case of a fixed-time traffic signal chiefly because it operates solely on a pre-time table for predicting the interval timings and does not respond to the different traffic conditions. The room for uncertainty is more in case of adaptive and actuated traffic signals that respond to the different traffic conditions, and this study is all about this. Here there is a base timing table, but the adaptive and actuated lights are likely to change as per the traffic conditions. It is a challenge to determine the signal interval's start and duration because of the uncertainties above. Thus, (Mahler and Vahidi, 2012) with the help of a probabilistic prediction framework handled the case with dubious information. As opposed to the study in this thesis, they engrossed themselves in cases where the present interval, as well as the average green and red time interval for any signal, were known. Based on this, the information they predict the likelihood of green over the planning horizon. By combining the crowdsource information, infrastructure sensor data, operating logic of signalised intersections and historical data they have succeeded to generate an average time-table.

A simple way of predicting the future switching times is by calculating the relative frequencies resting on the past cycles' switching times (Weisheit, 2014). This is a test approach which had been experimented by (Weisheit, 2014) on a signalised intersection's signal head situated in Dusseldorf. As per the test results, the switching times of 2000 cycles of the probabilities of the occurrence of the green ends were evaluated. Prediction accuracy of about 45% was reported amid the ratio between the complete number of cycles and the detected switching times. They categorised the detected switching times as per the related signal program that comprised of three varied programs with an aim to augment the possibility of occurrence. They used the data from the available detector to augment the possibility of occurrence. Support Vector Machines implemented the prediction of the switching times to have an improved prediction accuracy. These will help to study relationships between the traffic-associated data like the vehicle detection data or public transport along with the resulting switching times as per hyperplanes. This technique will broadly classify a series of objects into classes with an aim to keep the most prominent possible area surrounding the class boundaries to stay free from objects. The basis for the categorisation is a training data set that is corresponding. Through this, the algorithm will know about how the class boundaries develop. This algorithm attained a 73% prediction accuracy. There were miss classifications due to the frequency distribution about the switching times with regards to the corresponding traffic volumes for a cycle in its entirety. When the overlap area of the frequency distributions of a specific total traffic volume is greater automatically the prediction of the possibility of a wrong switching time will be higher. There can be an improvement in the prediction accuracy when it comes to determining the relative frequencies. This can be done by dividing the test data set and the training in accordance to the different signal programs. In fact, this resulted in the improvement of the prediction quality by about 83%. There is a scope to improve the prediction if its latency period is less than a second and this can be done through the data model that has been proposed for a brief latency period. The algorithm will use the times of signal edges as input variables, and this will include all detectors. Data models for short latency periods as compared to those for long latency periods reached an accuracy prediction of about 92% for the individual signal programs. This includes switching times amid the latest and the earliest.

(David and Courage, 2002) assessed two models of prediction- the target degree of saturation strategy and the queue service time–green extension time strategy to predict average phase times in actuated modes. As per the above strategy, the actuated phases will help in facilitating an efficient signal operation when it operates at a predictable degree of saturation, at times being little below capacity. This is not applicable in many parts of Sharjah during the peak hours. The principal objective of an actuated phase is in terminating the right-of-way immediately after the opening queue of cars are served. The degree of saturation here will be 100%, and there will be a termination of the right-of-way the moment the queue was served. The latter strategy throws light on the fact that the estimation of the length of an actuated phase can be made by summing up the time of the queue service, the inter-green (all red and yellow) time and the green extension time (David and Courage, 2002). Besides, the queue service time also represents the total time needed for serving the opening standing queue. To estimate the queue service times, the concept of the queue accumulation polygon can be applied by deterministic models. **Figure 39** shows a polygon in a triangle shape showing a uniform rate of departures on green and arrivals on red. The shape of this polygon will help to determine the queue service time along with other measures. This shape, however, can get complicated in response to the conditions on the field resulting in nonuniform departures or arrivals thereby leaving room to compute the queue service time under different conditions accurately. This polygon may be a strong pointer of the queue service time, but it is not much useful to determine the green extension time (David and Courage, 2002).

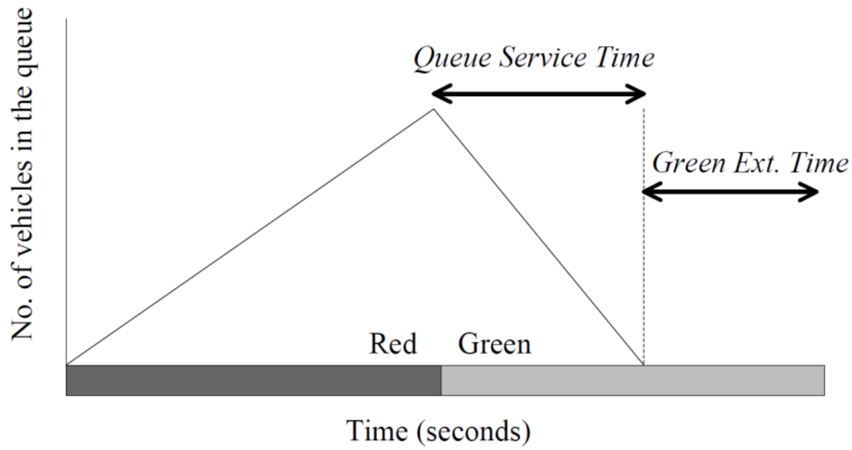


Figure 39: Sample queue accumulation polygon (David and Courage, 2002)

To conclude it may be stated that, a presentation algorithm chiefly rests on the prediction technique used for creating it. When the prediction method used is highly accurate, automatically the presentation algorithm will perform better when it comes to displaying a countdown timer. Studies and research on the prediction of a traffic signal in the recent decades have gone up rapidly, and different signal system models have been created in this field for proper investigation.

5.2.2. Signal time prediction in connected vehicles

New technologies are being introduced through which traffic signals would be able to communicate with cars having the same technology embedded in them. This would allow the driver to predict the time the car would take in reaching the nearest intersection and allows to manage the speed in such a way that there are minimum braking and minimum stopping. The result would be much less fuel wastage and less pollution.

One of the systems which enables this kind of communication is called Green Light Optimal Speed Advisory (GLOSA). This system works according to an algorithm which provides the car information about the speeds it should maintain in order to minimize the waiting time at the upcoming signal. This would not just reduce the wastage of fuel and the number of accidents but also bring about the lesser delay in traffic. It is estimated that around 10% of traffic delays amounting to 300 million vehicle-hours, on major roads are due to traffic signals (Asadi and Vahidi, 2009). The cost of it all, not just in terms of money and time but also environmental pollution, must be staggering.

Since very few vehicles are endowed with this technology, the system has to take information from the connected vehicles and then use it to gain an estimate about the whole cavalcade of cars that are approaching the traffic lights like a platoon. For the identification of the lead vehicle, a 'time loop technique' is proposed. This technique would do the job of estimating time and distance covered even if there were complicated and complex messages being exchanged between vehicles.

GLOSA functions upon Car-to-X (C2X) communication technology. Other technologies that are used for this purpose are the Map Data Message (MAP) and Signal Phase and Timing Message (SPAT). SPAT messages are used by GLOSA system to make accurate predictions. SPAT provides information about each lane of an intersection regarding its current and next phase along with its current state. MAP, on the other hand, gives inputs about the topology of an intersection (Stahlmann *et al.*, 2018).

By simulating real-life conditions, the impact of GLOSA was tested. The results were in two parts: for the situation when the simulation had only one car on the road and when there were other vehicles. In the former scenario, the fuel consumption came down by 22% and in the latter by 8% (Katsaros, 2011). To get an even clearer picture of the impact GLOSA would have in real-life situations, Xia et al. conducted a test in which they used a 4G LTE-based GLOSA prototype system. The testing took place at Berkeley in California. The results showed a 13.6% reduction in real-world situations while it was 14% in simulation (Xia, Boriboonsomsin and Schweizer, 2012).

Other tests have been done to measure the reduction of CO2 emissions due to decreases in waiting time and stoppages. One of these computed the change based on various percentages of vehicles among the total traffic being equipped with GLOSA. This study discovered that when 100% of vehicles are equipped with GLOSA, the reduction in CO2 emissions is 10%. Furthermore, with 40% vehicles and 50% of traffic lights equipped, the dip in CO2 emissions is 5% and 30% in waiting time (Lebre *et al.*, 2015).

The speeds prescribed to the drivers by the GLOSA system is meant to minimize the fuel wastage. But that can't be the only criteria. Otherwise, the system may prescribe speeds that are too high to be used on the road. To prevent this occurrence, the system has a pre-determined speed spectrum within which the speed suggestions have to fall. Also, in most systems, the speed suggested to the driver for minimizing the fuel consumption has to be constant from the moment of contact being established between the vehicle and the signal to that particular intersection. It is challenging to maintain the same speed for a long stretch of road. Hence, many papers on this topic have come to suggesting systems that, rather than asking for one speed to be maintained throughout the stretch of road leading to the intersection, allow for braking and changes to speed as well. This is a much more preferable option as a driver is almost certain to alter his speed travelling on the road due to the presence of other vehicles. Therefore, it makes much more sense to give instructions in response to a change of trajectory rather than just the speed.

Research by (Feng *et al.*, 2015) presented a different type of algorithm which works by taking inputs from various vehicles connected through the GLOSA system rather than just one. This algorithm simultaneously takes into account the information coming from vehicles approaching the intersection from various directions and manages to produce an optimum result in which much lesser time and fuel is wasted. Researches have suggested that this algorithm can bring down delays by 16.33% at its most efficient rate. Another interesting fact is that vehicles are now equipped with the latest sensors that provide immediate and detailed information about the metrics of speed and distance and shares it with all the cars that are connected to the system. The information can now be shared between different vehicles, and this is known as Vehicle-to-vehicle (V2V) communication. The network is called vehicular ad-hoc networks (VANETs).

It's unlikely that in heavy traffic, all the vehicles would be endowed with GLOSA. So, the question arises, would one connected vehicle be able to steer the whole traffic in a practical way? There is an algorithm called the "estimation of location and speed" can help in such a situation. It divides the road segments into three parts: the queuing region, slow-down region and free-flow region. After this, new algorithms are again used for all the three regions to pin down the location and speed of the unequipped vehicles. This way a major change can be brought about in the traffic flow (Feng *et al.*, 2015).

All the tests conducted to study the impact of GLOSA technology have suggested that it would substantially reduce the time of journey, fuel consumption and as a corollary, the emission of greenhouse gases. Most of these studies have been conducted in simulated environments, but some have incorporated elements of real-life scenario as well.

It becomes clear that if the contact between the traffic signal and the vehicle is established when the latter is around 500 meters away from the traffic intersection, the guidance provided to the vehicles in terms of speed can help in reducing the time and fuel-usage of the journey. But some studies have gone ahead and provided algorithms which would be able to not just suggest a constant speed to reduce time but also the trajectory, the braking and the accelerating also. Furthermore, rather than just communicate with one vehicle, the system can work with various vehicles at the same time, coming from different directions and manage their transit for overall improvement in transport.

5.2.3. Recommended prediction method

The aim of this study was for the prediction method to serve as a base for the presentation algorithm so that the algorithm could be evaluated. The countdown timer in the study model presented remaining red time. This choice was made considering that the red time interval for an approach is equal to the summation of other approaches including green interval time plus inter-green times.

Two simple approaches were introduced to predict the green time. The first method was to take the proportion of the actual green time over the max green time in the previous phase in the same cycle and assume that the next phase should have the same proportion of the green time. The formulas were developed to predict the green time for three approaches, where the total remaining red time presented for the fourth approach would be the sum of those green times and inter-green times. In this case, the equation to calculate the green time for each approach was as follows:

$$G2_f = G1_a/G1_{max} * G2_{max}$$ **Equation 1**

$$G3_f = \frac{\left(\frac{G1a}{G1max}\right)+\left(\frac{G2a}{G2max}\right)}{2} * G3_{max}$$ **Equation 2**

$$G4_f = \frac{\left(\frac{G1a}{G1max}\right)+\left(\frac{G2a}{G2max}\right)+\left(\frac{G3a}{G3max}\right)}{3} * G3_{max}$$ **Equation 3**

Where:

G1 Green Time for phase1

G2 Green Time for phase2

G3 Green Time for phase3

G4 Green Time for phase4

f Forecasted

a Actual

The second method was to assume that the green time of the phase in the running cycle would be equal to the green time of the same phase in the previous cycle. In this method, the following equation was developed:

$$Gx_f(n) = Gx_a(n-1)$$ **Equation 4**

Where:

x Phase number

n Cycle

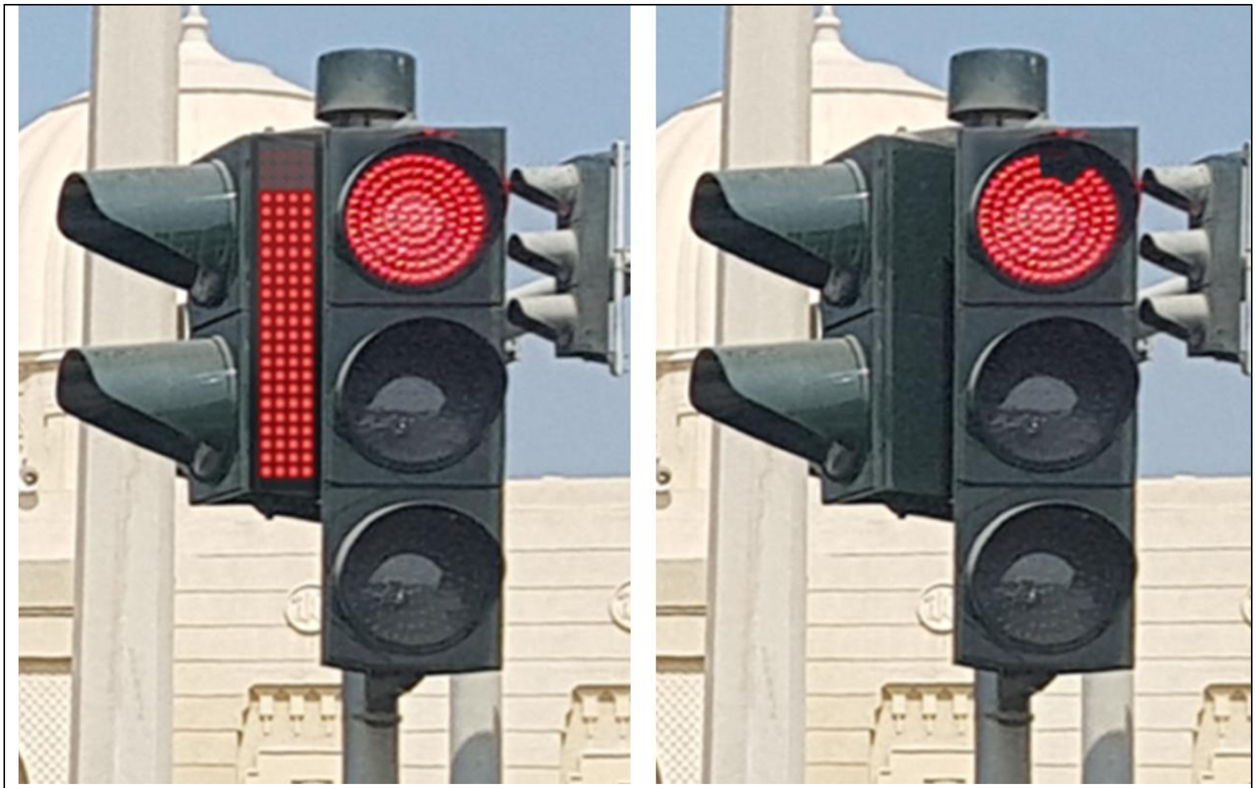
f Forecasted

a Actual

When comparing the results of those two methods, both prediction methods gave the same range of results. The 100% accuracy of the prediction was between 20% and 30% of the total result. On average, 80% of the prediction was $\pm$20% of the actual green time and 15% was $\pm$40%. A better prediction method and design of the signal plans can lead to better performance of the algorithm. In this study, both methods proved accurate, and the second method was chosen to evaluate the proposed algorithm just because it was easier to program in the VISVAP program (which is part of the VISSIM software) and to avoid any programming problem which is not a major part of this study.

5.2.4. Remaining red time algorithm

SCT main purpose is to indicate drivers or pedestrians about the remaining time to onset of the next signal phase. In the case of actuated signals, it is difficult to predict exact timing because of the various factors which affect phase changes. The prediction method in most cases is not accurate 100% of the time for actuated control systems. Therefore, in this study, we did not use the typical numeric SCT. Instead, the percentage of remaining red time was presented as descending bars or circles **Figure 40**.



Bar countdown timer　　　Circular countdown timer

Figure 40: Different countdown timers for actuated signals

The algorithm for remaining red time was designed so that it would start after the end of the running amber interval. It uses the predicted time, signal logic, and data stored in the controller such as minimum and maximum green time to calculate a Speed Factor (SF) to change the speed of the counter. If the actual green time is longer than the predicted time, SF will be less than 1.0 and the speed of the remaining time counter will be reduced. If SF is larger than 1.0, the counter speed will be increased. The SF starts with a value of 1.0 and may change many times during a cycle. The number of changes depends entirely on the logic of the signal timing. The initial speed of the countdown timer depends on the previous cycle time. **Equation 5** was used to calculate the initial speed for the countdown timer. The unit of speed of the countdown timer is per cent per second, where (per cent) refers to the countdown timer device display; which means 100% refers to a full bar and circle display and 0% refers to the state where the bar or circle are entirely off.

$$S_0 = \frac{100}{CT_{i-1}}$$ **Equation 5**

Where:

S_0 Initial speed (%/s)

CT_{i-1} Previous cycle time (s)

Equation 6 was used to calculate the remaining red time percentage presented on the countdown timer, which is the equivalent percentage of the bar or circular countdown timer displayed taking into consideration that Remaining Time Percentage (RTP) starts as 100% in all cases.

$$RTP_i = RTP_{i-1} - (S_i * SF_i)$$ **Equation 6**

Where:

RTP Percentage of remaining red time

S Speed

SF Speed factor

i Seconds

The speed factor calculation changes at the beginning of each interval or when the actual green time exceeds the predicted green time, whichever comes first. **Figure 41** shows a flowchart of the algorithm for ta ypical cycle time.

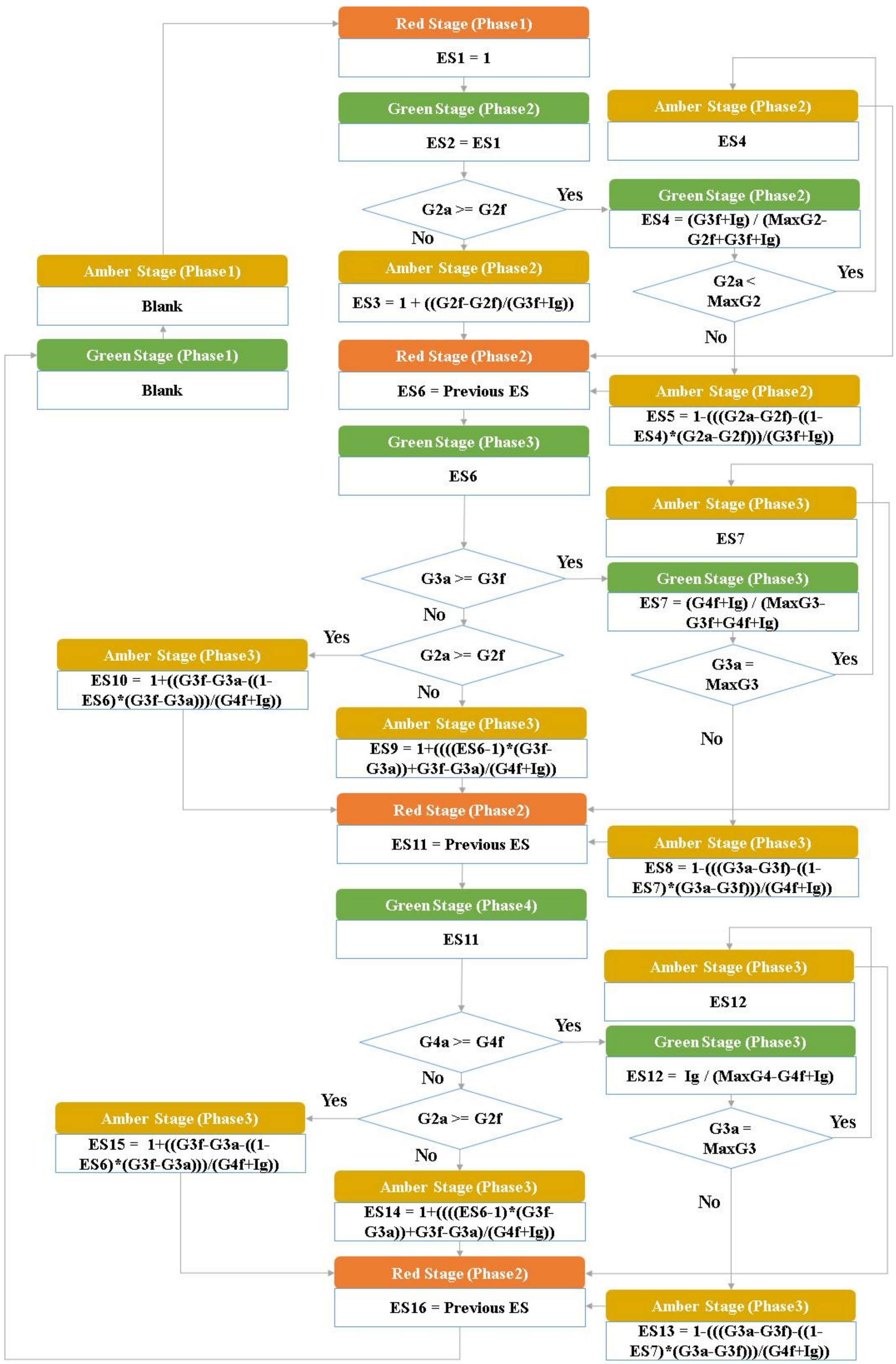


Figure 41: Calculation of the remaining phase time in actuated signal control

5.3. Evaluating the algorithm under different vehicle demands

The difference between the proposed type of countdown timer in this study and more standard types is that in this case, the countdown timer changes speed during the waiting time. This feature can be the key to figuring out relevant performance measures. The purpose of the performance measure, described in this chapter, is to check the behaviour of the countdown timer in different situations. To gain a better understanding of the behaviour of the countdown timer, the algorithm was tested in different traffic pattern using the simulation software VISSIM. First, it was tested on the approach coming from a signalised junction where the traffic approaches in platoons. Then it was tested on a second approach, which was receiving free flow and stochastic traffic flow. The difference between these two situations exhibited in the nature of the groups of vehicles arriving at the intersection. The first scenario resulted in all vehicles in the simulation arriving as a large group at the same time. The free-flowing traffic scenario applied random probability distribution for when the individual cars would arrive. This may especially affect group timing in non-peak hours. Those two approaches covered the major traffic demand. The third situation applied the algorithm to a minor approach.

The performance measures depend on speed changes which lead to an acceleration or deceleration in signal changes. In each cycle, there are many speeds and accelerations. The idle case is when the speed remains the same from the beginning of the red interval until the end of the same interval. Based on that, four types of performance tools have been used to check the behaviour of the algorithm. Two of them are related to the acceleration of the counter and the other two related to the speed of the counter. The two performance measure which is related to the acceleration are: Acceleration Error (AE) and Acceleration Percentage Error (APE), which can be calculated using **Equation 7** and **Equation 8**, and the two which are related to the speed of the counter is the Relative Speed Error (RSE) and Speed Difference Error (SDE) which can be calculated using **Equation 9** and **Equation 10**

Acceleration Error (AE) $=\frac{|\Delta S_a|}{\Delta t}$ **Equation 7**

Acceleration Percentage Error (APE) $= \frac{AE}{S_a}$ **Equation 8**

Relative speed Error (RSE) $= \frac{S_f}{S_a}$ **Equation 9**

Speed Difference Error (SDE) $= \left|S_f - S_a\right|$ **Equation 10**

Where:

S_a Actual speed

S_f *Forecasted speed*

t Time in seconds

Figure 42 shows a sample performance of the countdown timers using the proposed algorithm in one single cycle, where the forecasted values can be compared with the actual. It shows the differences between the speeds, and in this cycle, there were three changes. The changes happened at the second 36, 67 and 92. **Table 56** shows the performance measure results for this sample.

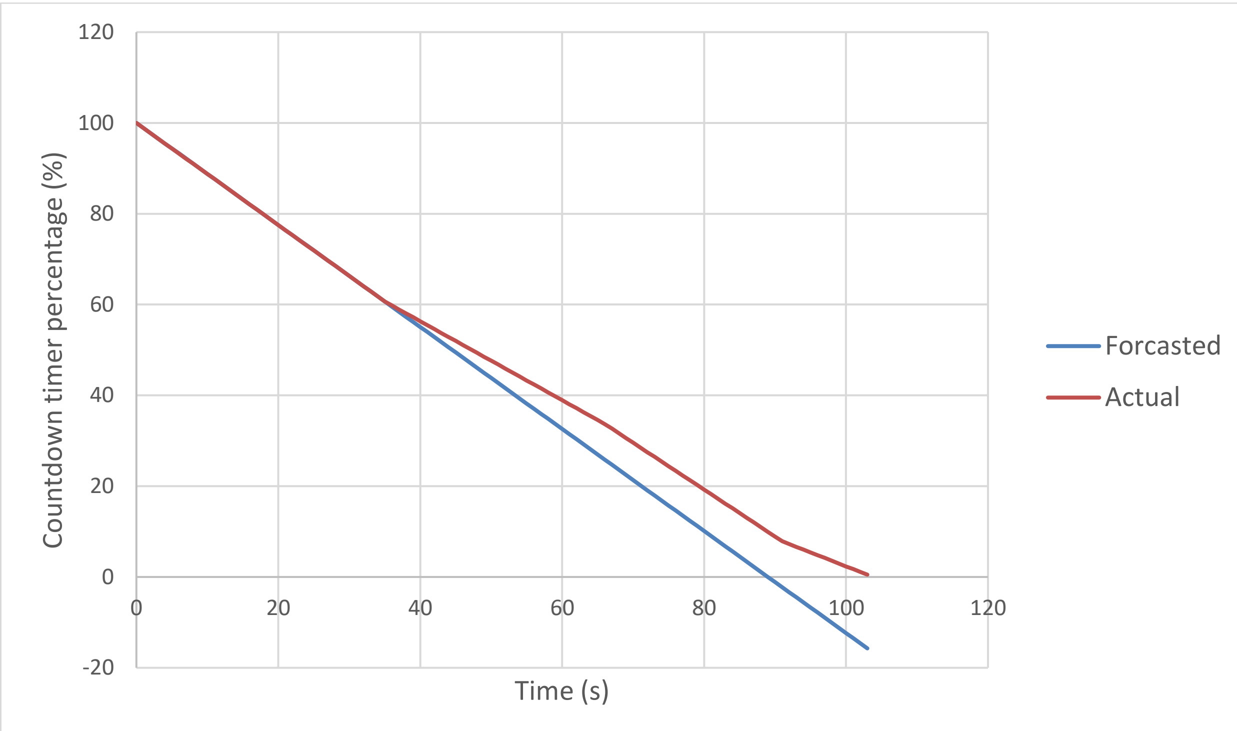


Figure 42: SCT algorithm behaviour for one typical cycle time

Table 56: Performance measures for one simple cycle time

Time (S)	AE %/s²	APE %	RSE %/s	SDE %
36	0.3	22	0.25	23
67	0.2	18	0.09	8
92	0.4	41	0.51	46

Figure 43 shows the AEs during the day for each approach. The error increases in non-peak hours, and it is almost zero in peak hours for all scenarios. The reason for that progression is because in peak hours the traffic reaches maximum demand, which leads to maximum time allocated for each movement. In this case, the prediction in peak hours can be accurate 100%, and this will lead to better performance of the algorithm. The APEs results were similar to AEs as shown in **Figure 44**.

Table 57 shows the distribution of the AE for each approach. Findings on the major approach from free flow traffic showed the most AEs among the three scenarios (1,250 AEs). In general, however, AEs were similar between the three scenarios. Most of the AEs were less than 0.5%/s^2. For the major approach from a signalised junction, 78% of the AEs or acceleration percentage error was less than 0.5%/s^2. For the major approach from free flow traffic and the minor approach, 76% and 77% of the AEs were less than 0.5%/s^2 respectively.

Table 58 shows the distribution of the APEs for each approach. The APE is entirely dependent on the AE. Therefore, the number of APEs for each approach is exactly the same as the AEs. Most of the APEs were less than 60%. For the major approach from a signalised junction, 90% of the APEs or acceleration percentage error were less than 60%. For the major approach from free flow traffic and the minor approach, 83% and 84% of the AEs were less than 60% respectively. In general, however, APEs were similar between the three scenarios.

Table 57: Acceleration error distribution for each scenario

AE	Major approach after the signalised junction		Major approach after free flow		Minor approach	
	Numbers	**%**	**Numbers**	**%**	**Numbers**	**%**
0.0-0.5	915	78%	953	76%	911	77%
0.5-1.0	193	17%	167	13%	175	15%
1.0-1.5	40	3%	60	5%	49	4%
>1.5	20	2%	70	6%	44	4%
Total	**1168**	**100%**	**1250**	**100%**	**1179**	**100%**

Table 58: Acceleration percentage error distribution for each scenario

APE	Major approach after the signalised junction		Major approach after free flow		Minor approach	
	Numbers	**%**	**Numbers**	**%**	**Numbers**	**%**
0%-30%	747	64%	869	70%	767	65%
30%-60%	302	26%	166	13%	220	19%
60%-90%	74	6%	110	9%	93	8%
>90%	45	4%	105	8%	99	8%
Total	**1168**	**100%**	**1250**	**100%**	**1179**	**100%**

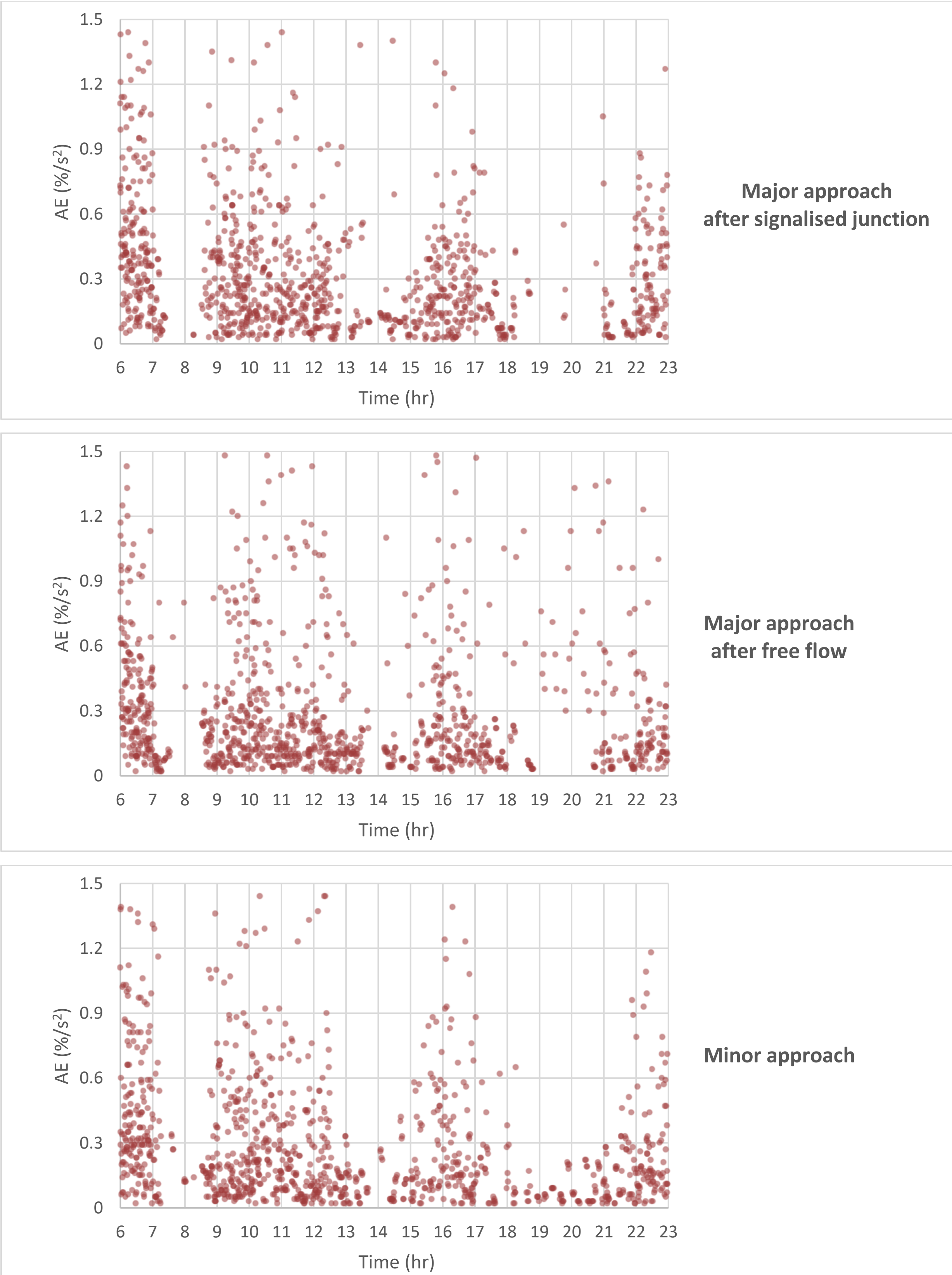
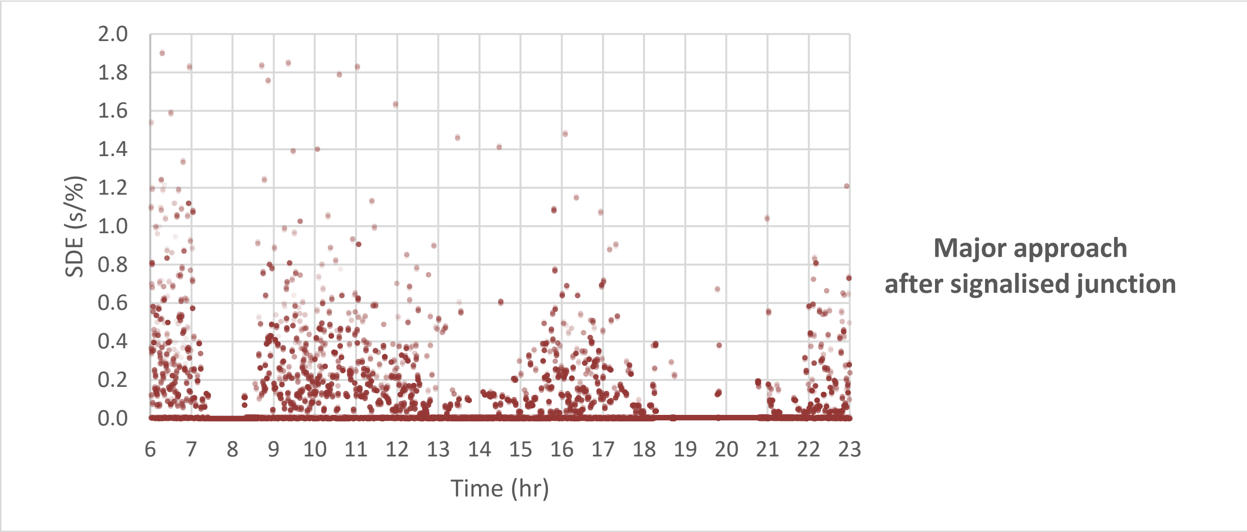
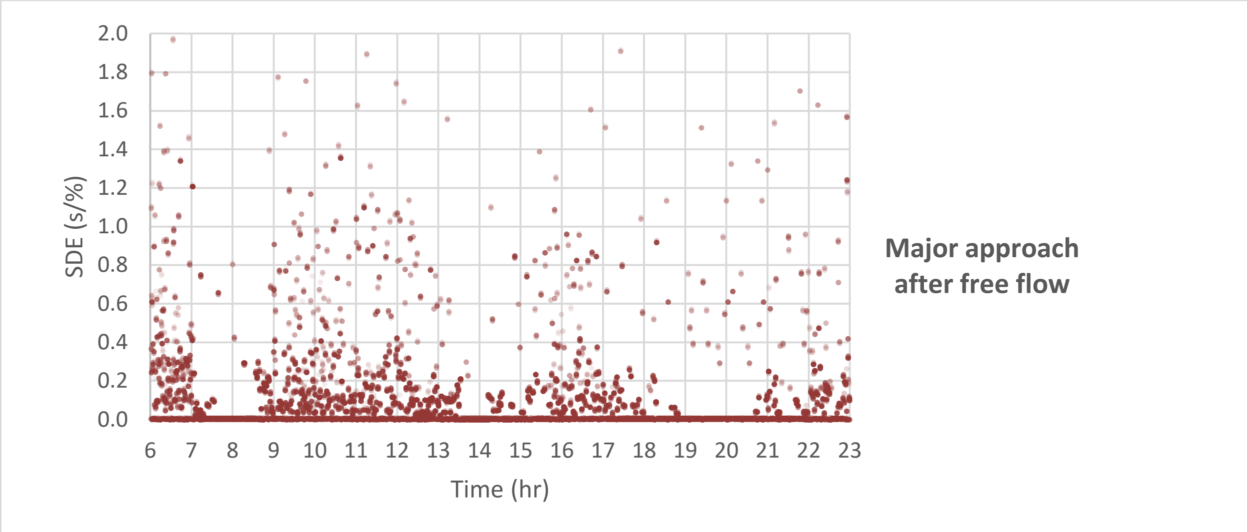


Figure 43: Prediction error measured by acceleration error for different vehicle demand (by the time of day and approach)

Figure 44: Prediction error measured by acceleration percentage error for different vehicle demand (by the time of day and approach)





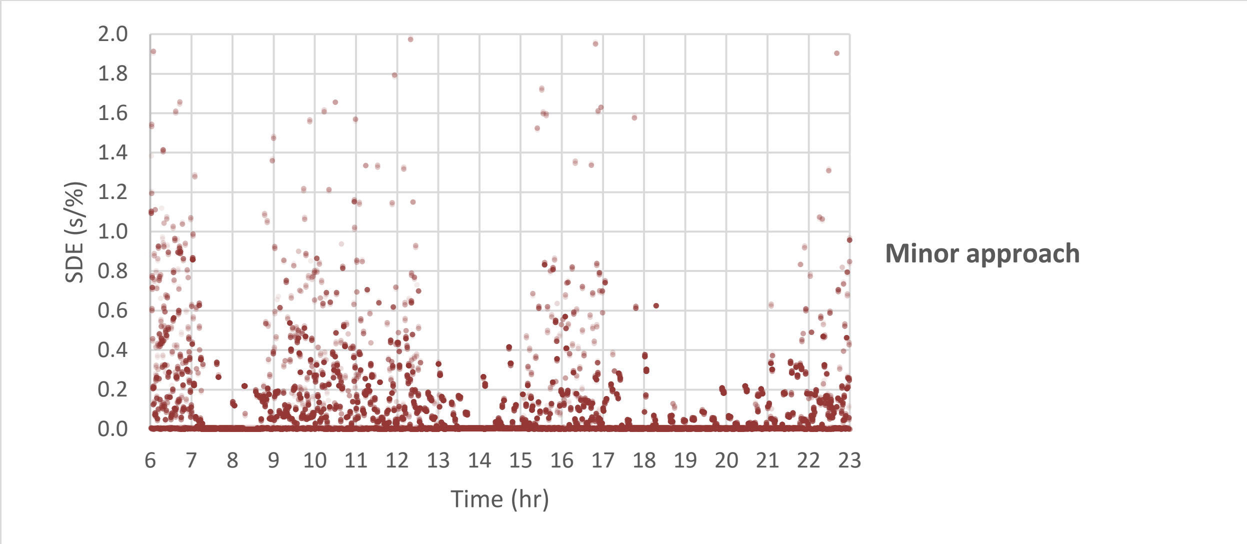


Figure 45: Prediction error measured by speed difference error for different vehicle demand (by the time of day and approach)

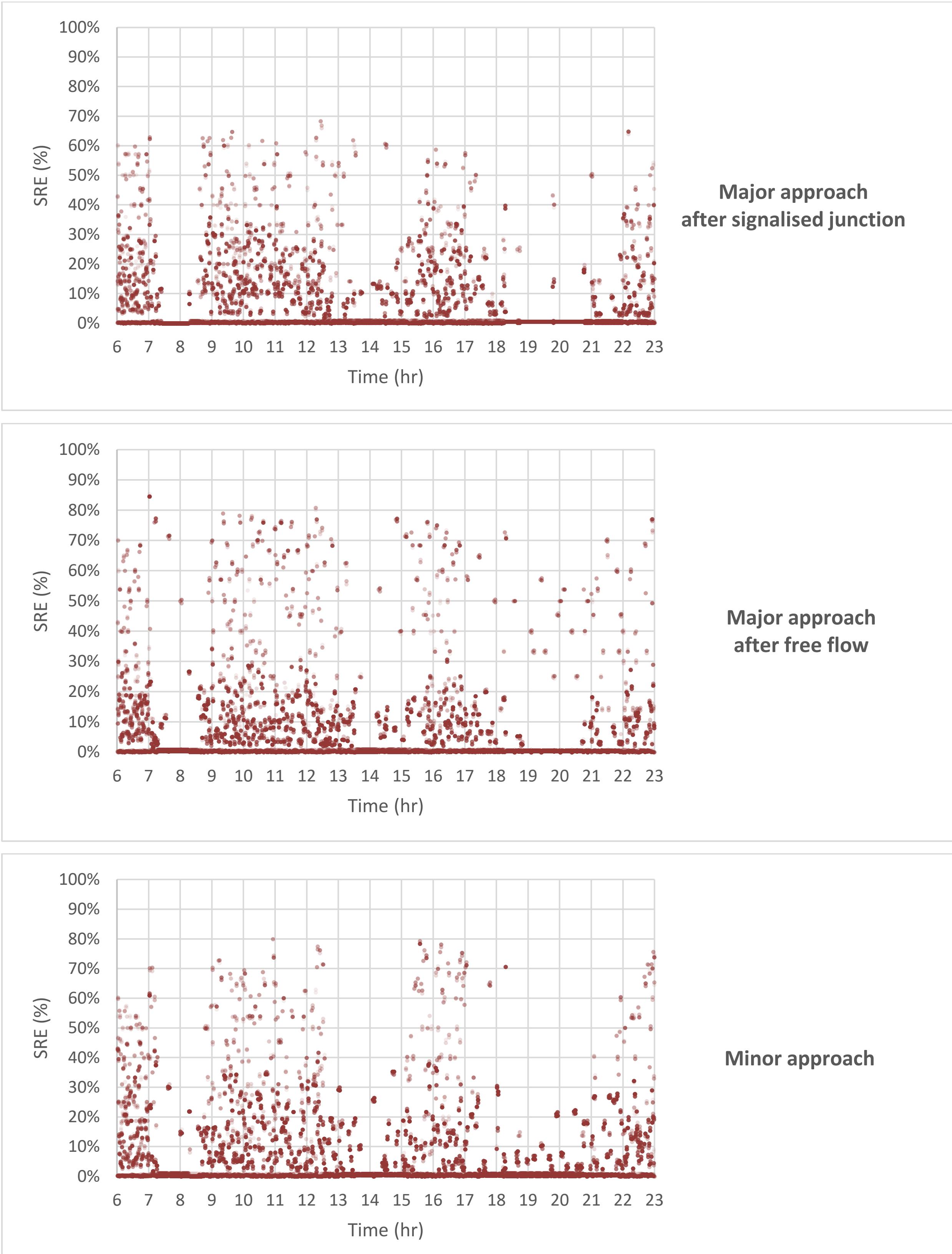


Figure 46: Prediction error measured by speed relative error for different vehicle demand (by the time of day and approach)

Table 59: Counter speed distribution for each approach during the test period

Speed (s)	Major approach after the signalised junction		Major approach after free flow		Minor approach	
	Numbers	%	Numbers	%	Numbers	%
0-0.5	139	0.3%	857	2%	770	1%
0.5-1.0	19,938	42.7%	11,209	25%	35,970	68%
1.0-1.5	23,015	49.3%	29,150	65%	13,498	25%
1.5-2	2,702	5.8%	2,713	6%	1,978	4%
>2.5	861	1.8%	815	2%	747	1%
Total	**46655**	**100%**	**44744**	**100%**	**52963**	**100%**

Table 60: Speed difference error distribution for each approach during the test period

SDE (%/s)	Major approach after the signalised junction		Major approach after free flow		Minor approach	
	Numbers	%	Numbers	%	Numbers	%
0-0.2	39,498	85%	37,826	85%	44,768	85%
0.2-0.4	4,335	9%	3,884	9%	4,776	9%
0.4-0.6	1,712	4%	9,10	2%	16,46	3%
>0.6	1,145	2%	2,144	5%	1,754	3%
Total	**46,690**	**100%**	**44,764**	**100%**	**52,944**	**100%**

Table 61: Speed relative error distribution for each approach during the test period

SRE	Major approach after the signalised junction		Major approach after free flow		Minor approach	
	Numbers	%	Numbers	%	Numbers	%
0% - 10%	36,340	78%	34,413	77%	39,605	75%
10% - 20%	5,080	11%	5,871	13%	6,382	12%
20% - 30%	2,935	6%	1,811	4%	3,564	7%
>30%	2,335	5%	2,669	6%	3,393	6%
Total	**46,690**	**100%**	**44,764**	**100%**	**52,944**	**100%**

Regarding the speed of the countdown timer during the test period, a relationship was observed between the peak time and the speed of the countdown timer. Speeds were constant at the peak hours. The reason could be similar to the reason stated previously. **Table 59** shows the distribution of the counter speed during the test period for each approach. Most of the speeds were between 0.5 and 1.5 $s^2/\%$. Speed difference error (SDE) is the first type of error related to the speed of the countdown timer. **Figure 45** shows the distribution of the SDEs during the test period.

Table 60 shows the distribution of the SDEs during the test period for each approach. Mostly the difference between the actual speed and forecasted speed were less than 0.2%/s (85%). To evaluate this result, the speed distribution should be considered. The detail results for the speed distribution showed that around 85% of the speeds were between 0.9%/s and 1.3%/s. for a better understanding of these results the, it was essential to check the relative speed distribution. **Figure 46** and **Table 61** showed the distribution of speed relative distribution (SRE). Again, most of the errors were in non-peak time. Around 90% of the SREs were less than 20%.

6. ‘Human’ response to proposed countdown timers ‘machine interaction‘

It was essential to define a method to evaluate the developed prediction technology and to define an acceptance tolerance. To accomplish that, it was necessary to identify what exactly should be evaluated. The change in the speed of the countdown timer is the main difference between the countdown timers used for fixed-time traffic signals with digit display and the ones presented in this study which work under actuated mode. This difference is due to changes in the time allocated for the intervals, where it is fixed in standard countdown timers. Which means the change in speed is key to defining an evaluation method. A countdown timer will be perfect and 100% accurate if there is no change in signal phase speed. However, even in actuated signals, there are some changes which can be considered as acceptable and/or not observable by drivers. To define those factors and obtain driver perceptions, a questionnaire was prepared which included videos showing a countdown timer reflecting different speed changes. The idea was to collect participants’ observations when changes occurred. Then, finding out which changes were acceptable to or observed by drivers assisted in developing an evaluation method which could be used to assess countdown timers and show the acceptance level. An online survey questionnaire was distributed through email to random groups including some specialists in the field of traffic control. A total sample of 363 responses has been collected.

6.1. Questionnaire structure and question design

The evaluation method questionnaire was prepared using Google forms and divided into three main parts. The first part contained demographic and general questions including age and gender of the participants. The reason for collecting this information was to check whether there was any age or gender effect on the answers. Also, two general questions were asked before starting the videos. The first question asked if the participant held a driving license. The second question asked if the participant worked in the field of traffic signals. It was essential to collect responses from specialists in the field of the study and check if there is any significant difference between general users and specialists.

After the demographic and general question section, the second part of the questionnaire was simulations and video clips showing countdown timers. Time change possibilities and cases can be numerous, and scenarios of time changes are virtually unlimited. For example, one simulation showed more than 1,000-time changes during the simulation period. To limit the study options, two main criteria were included in the videos, the speed of the timer and signal speed changes. The main goal of this survey was to find out the acceptable speed and speed change which is in another word the acceleration. Therefore, three speeds were chosen to be included in the survey (Slow, Med, and Fast). From the findings of the simulations described in the previous chapter, around 90% of the speed changes were less than 60%/s^2. Therefore, 60% change was chosen as one of the speed changes for the survey. To get a proper trend and enough data to draw a graph representing an acceptable range, half of the 60% level was selected.

One additional criterion was added to the scenarios, the shape and type of countdown timer. Two types of countdown timers had been chosen to be included in the questionnaire: the rectangular or bar countdown timer and the circular countdown timer (**Figure 40**). Those two types are the most common and most natural ways of presenting the remaining time, based on information from traffic signal manufacturers. In this case, with three different speeds, two different speed changes in both directions and two types of countdown timers, a total of 24 videos were prepared for the questionnaire. Each video had a length between 9s and 28s. After each video, there was a question regarding participants' observations about the speed change. The answer gave four options (big change, average change, small change, and didn't change). A demo questionnaire including 12 videos had been prepared and sent to a few participants to get feedback about the time needed to complete the questionnaire. Most of the test participants became bored in the middle of the questionnaire and decided to answer the questions without watching the videos. To solve this problem, the number of videos has been decreased to six videos in each questionnaire. In this case, with 24 different video scenarios, a total of four different questionnaires has been prepared and distributed. The order of the videos was chosen to list three videos of the same type of the countdown timer first. Each video with same speed and different speed changes. The speed changes in each questionnaire included at least one 60% and one 30% speed change to make sure that the participant was able to see the difference. **Table 62** shows how the videos have been distributed in the four questionnaires.

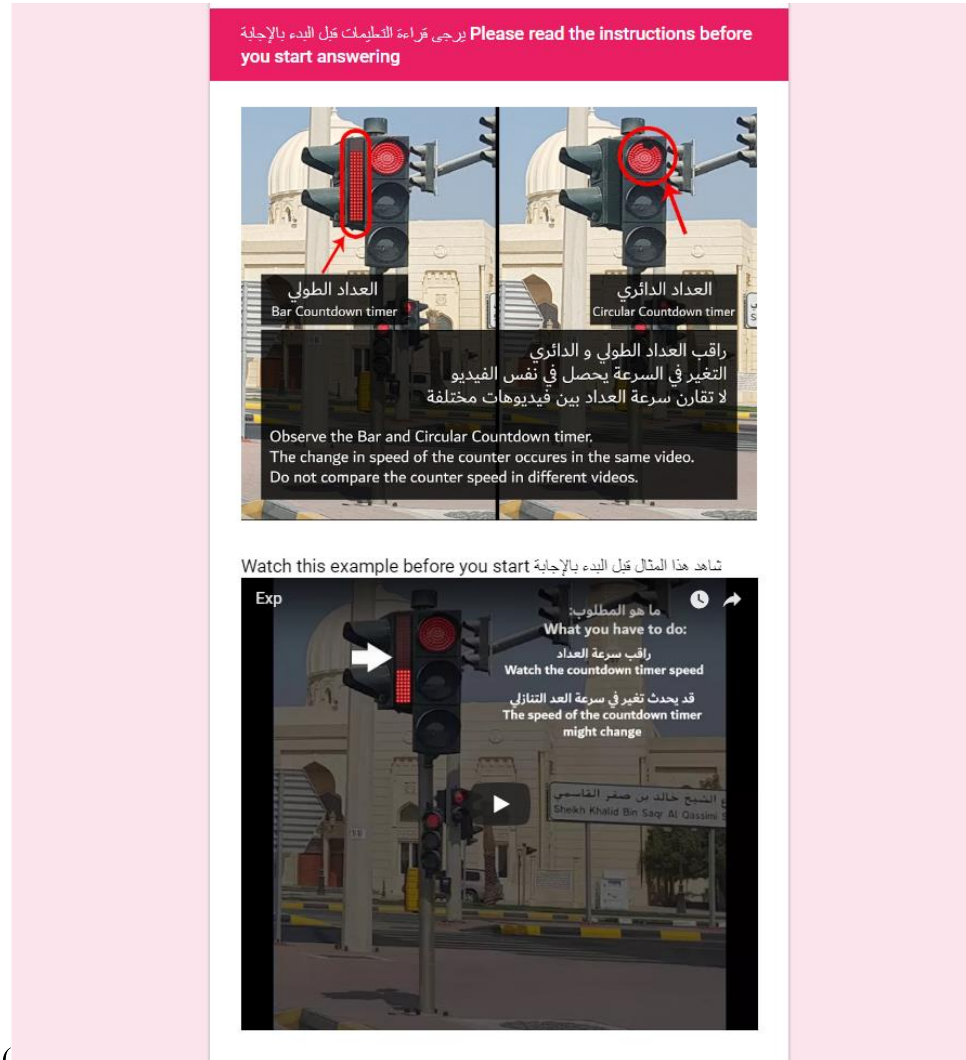
The last part of the questionnaire was general questions about the videos shown in the survey. The first question checked which presentation shape would be more comfortable to communicate the remaining time. Participants had a choice of a bar countdown timer or a circular countdown timer or both. The second question was whether participants thought that this device could be useful even if there were a change in its speed. The answer was scaled from 1 (not useful) to 5 (very useful). This question was included to gain general perceptions about accepting speed changes in the countdown timer display. The next question dug deeper, asking about the level of speed change which would be acceptable. Four answer options were given for this question: three taken from the videos (small changes, average changes, and big changes), and the fourth was all speed changes are acceptable. The last question asked if participants would recommend this type of countdown timer, and answer type was like the second question [scaled from 1 (not useful) to 5 (very useful]. At the end of the questionnaire, a non-compulsory comments box was provided for open-ended comments. All questions and explanations were created using both the English and Arabic languages.

Table 62: Video clips order in the distributed questionnaire

	Questionnaire 1		Questionnaire 2		Questionnaire 3		Questionnaire 4	
	Section 1	**Section 2**	**Section 1**	**Section 2**	**Section 1**	**Section 2**	**Section 1**	**Section 2**
Video No 1	Slow, Circular, -60%	Slow, Bar, -60%	Slow, Circular, 30%	Slow, Bar, 30%	Fast, Circular, 30%	Fast, Bar, 30%	Medium, Circular, 30%	Medium, Bar, 30%
Video No 2	Fast, Circular, -30%	Fast, Bar, -30%	Slow, Circular, 60%	Slow, Bar, 60%	Fast, Circular, -60%	Fast, Bar, -60%	Medium, Circular, -60%	Medium, Bar, -60%
Video No 3	Medium, Circular, 60%	Medium, Bar, 60%	Slow, Circular, -30%	Slow, Bar, -30%	Fast, Circular, 60%	Fast, Bar, 60%	Medium, Circular, -30%	Medium, Bar, -30%

6.2. Survey analysis

The survey was created using Google forms and distributed online using a shared link. Such online surveys are easy to access, especially from smartphones so that participants can participate directly by using their smartphone at any time. This method gave the researchers a fast and cost-effective way of distributing and collecting survey data. Also, it was easy to reach specific groups of participants to get well-distributed results. For example, in this research, it was essential to reach participants working in the field of traffic control as well as individuals outside the traffic field. At the same time, the disadvantage of such online surveys is that there might be a chance that participants will not understand the survey questions or even will answer without taking the survey seriously—although this can happen with offline surveys as well. To make sure that participants could understand the questions, especially regarding the videos and speed changes, a descriptive image and explanatory video were shown before starting to watch and answer the questions related to videos



(**Figure 47**). Even given these explanations and some direct contact with participants, exclusion criteria have been used to make sure that most of the answers are valid, practical, and reasonable. The exclusion criteria are described in the following section.

6.2.1. Exclusion criteria

To make sure that all forms provided realistic answers, some exclusion criteria were created for the 363 responses collected. Because this survey was an online type, we expected some responses not to be acceptable, and the exclusion criteria were based on common sense:

- In the video scenarios, there were two speed changes. Those changes had been chosen to have significant differences between them. Logically, the 30% change should not exceed in any case the 60% change. So, the first criteria for exclusion were that any 60% speed change, whether increasing or decreasing, should not be ranked less than any 30% speed change. By applying this criterion, 90 responses were removed.

- After removing those responses, researchers noticed that some participants appeared to be choosing the same answer for all videos. Those responses were not removed by applying the first criteria. It was determined that those participants seem to choose the same answer without watching the videos, so those responses were removed. By applying this second criterion, an additional 20 responses were eliminated. The total accepted responses after the removal based on exclusion criteria were 253 responses.

6.2.2. Demographic and general questions

Demographic data were collected to check if any significant changes came from characteristics of the participants. **Table 63** shows the demographic and general information about participants. Regarding age, three groups were created: less than 25 years old, 25 to 49 years old, and 50 to 75 years old. The vast majority of participants were between 25 to 50 years old (84%); 13% of them were less than 25 years old; only 3% of the participants were 50 years old or above. When comparing the age groups, there was no significant difference between them.

There was initially an age group of 75 years old and above, but it was not included because it was not easy to find drivers in that age group. While that age group could have slightly different outcomes than the survey sample, the percentage of that age group among drivers was too small to study in this project.

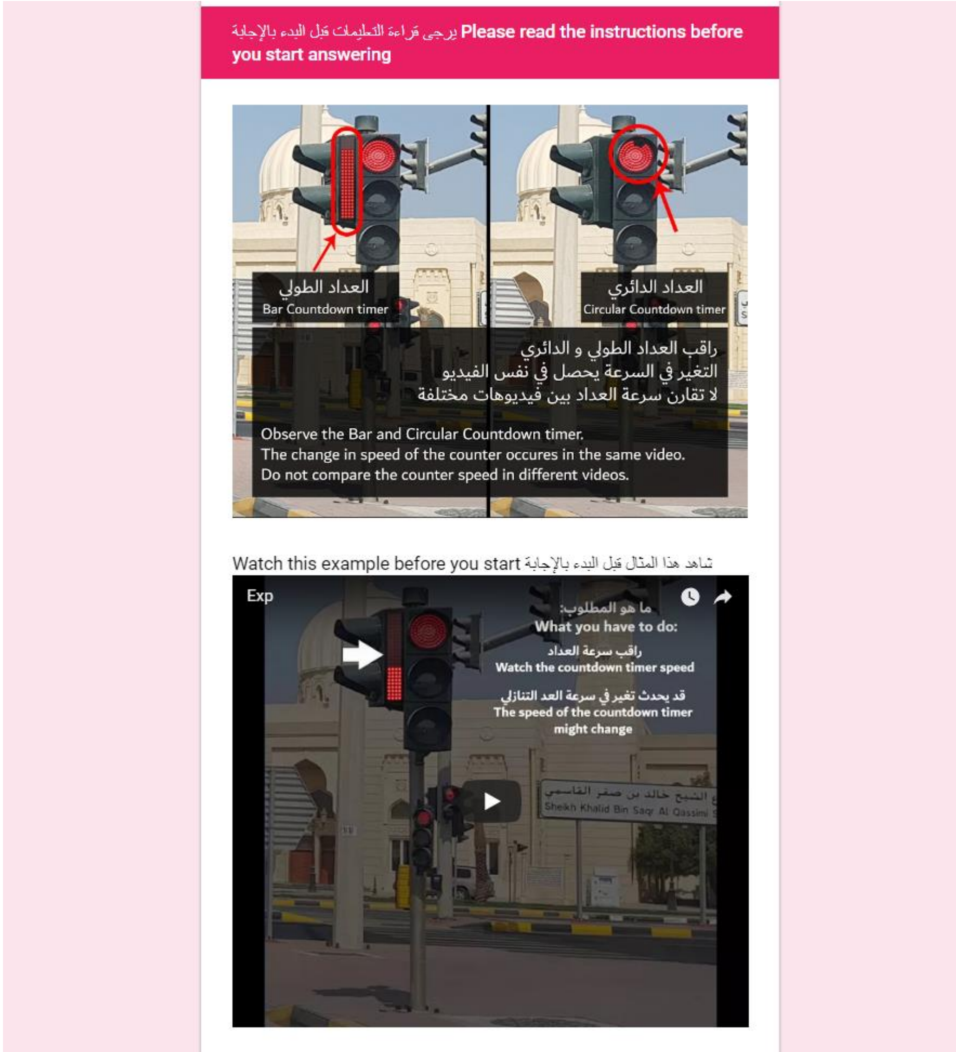


Figure 47: Explanatory image before starting the videos in the questionnaire

Regarding the gender of the participants, 73% were male, and 27% were female. There was no significant difference between answers based on gender. Another category was participants with and without driving licenses. Most participants held a valid driving license (98%). There was no significant difference in answers between participants with a valid driving license and those not holding a driving license.

The last category was for a specialist in the field of traffic signals. It was essential to know the opinions and observations of participants who work in the same field as this study and to differentiate them from answers of other participants. Answers revealed that 17% of the participants were working in the traffic and signal field, and answers revealed a significant difference in the three scenarios. All of them were in the circular type of the countdown timer and 30% change. The rankings were a bit higher than the group of participants who were not working the traffic field. The reason could be that they have a background in the technology so that they are more critical about the changes. However, in real life this percentage among the drivers would be much less than 17%; the percentage was higher in the study because related groups were sought out.

Table 63: Participant answers for the demographic and general questions

Age group		Gender		Holds driving License		Working in the field	
<25 Years	33 (33%)	**Male**	185 (73%)	**Yes**	247 (98%)	**Yes**	43 (17%)
25 - 49 Years	212 (84%)	**Female**	68 (27%)	**No**	6 (2%)	**No**	210 (83%)
50 - 75 Years	8 (3%)						
Total	253		253		253		253

6.2.3. Video results analysis

In total, 24 scenarios have been evaluated: six scenarios in each questionnaire, three scenarios from each type of countdown timer with at least one 60% change, and one 30% change. Similar scenarios from another type of countdown timer with same speed have been added to the same questionnaire. **Table 64** shows the results for each scenario. **Figure 48** shows that the most significant change observations were shown in the larger speed change scenarios, and the smaller change observations were shown in the smaller speed change scenarios. In comparison between countdown timer types, there was no significant difference.

In this research, two types of countdown timers were used. Appropriate shapes for countdown timers are limited because the presentation shape should be clear, intuitive, and easy for drivers and pedestrians to understand. At the same time, the shape must be practical from the manufacturing side. The main purpose of the survey was not to design a new type or shape for countdown timers, but to obtain perceptions and evaluate the use of existing timer types. The two types chosen for the survey were the most common types used in many cities such as Seoul and Amsterdam: the bar type and the circular type. One of the general questions after watching all scenarios was about which shape would be easier to understand in presenting the remaining time. Most of the participants (65%) chose the bar type of countdown timer as more comfortable to read. Only (17%) chose the circular type of countdown timer as more comfortable to read. An equal amount (18%) felt that both shapes are just as easy to read. Even given the big preference between those two shapes for the bar readout, there was no significant difference in the answers and indications. The answer option of “didn’t change” was not included in the comparison.

In real life, most drivers are not entirely focused all the time on traffic signals. This lack of attention applies to videos on the survey as well. Because there is a chance of participants not being focused on the videos at the time of the change, which happens quickly, they may not notice the change with bigger speed change. By looking at the results, this might be clear. In this case, it does not mean that they did not notice the change, so it was better not to include those answers not to confuse between the participants who did not notice the change and those who were not focused to notice the change.

Table 64: Participant observations for the video part of the questionnaire

Slow countdown timer								
Countdown timer type	**Circular**				**Rectangular**			
Speed change	**30**	**-30**	**60**	**-60**	**30**	**-30**	**60**	**-60**
Big Change	7	3	33	25	2	2	35	26
Average change	22	21	23	31	18	22	20	28
Small change	25	37	5	4	26	29	4	4
Didn't change	14	7	7	4	22	15	9	6
Total	**68**	**68**	**68**	**64**	**68**	**68**	**68**	**64**
Normal countdown timer								
Countdown timer type	**circular**				**Rectangular**			
Speed change	**30**	**-30**	**60**	**-60**	**30**	**-30**	**60**	**-60**
Big Change	6	2	23	36	3	3	20	38
Average change	10	10	24	20	13	14	22	21
Small change	29	32	2	6	25	25	6	4
Didn't change	20	21	15	3	24	23	16	2
Total	**65**	**65**	**64**	**65**	**65**	**65**	**64**	**65**
Fast countdown timer								
Countdown timer type	**Circular**				**Rectangular**			
Speed change	**30**	**-30**	**60**	**-60**	**30**	**-30**	**60**	**-60**
Big Change	2	0	15	27	1	0	19	33
Average change	14	13	26	17	16	13	16	14
Small change	25	41	5	7	22	34	8	5
Didn't change	15	10	10	5	17	17	13	4
Total	**56**	**64**	**56**	**56**	**56**	**64**	**56**	**56**

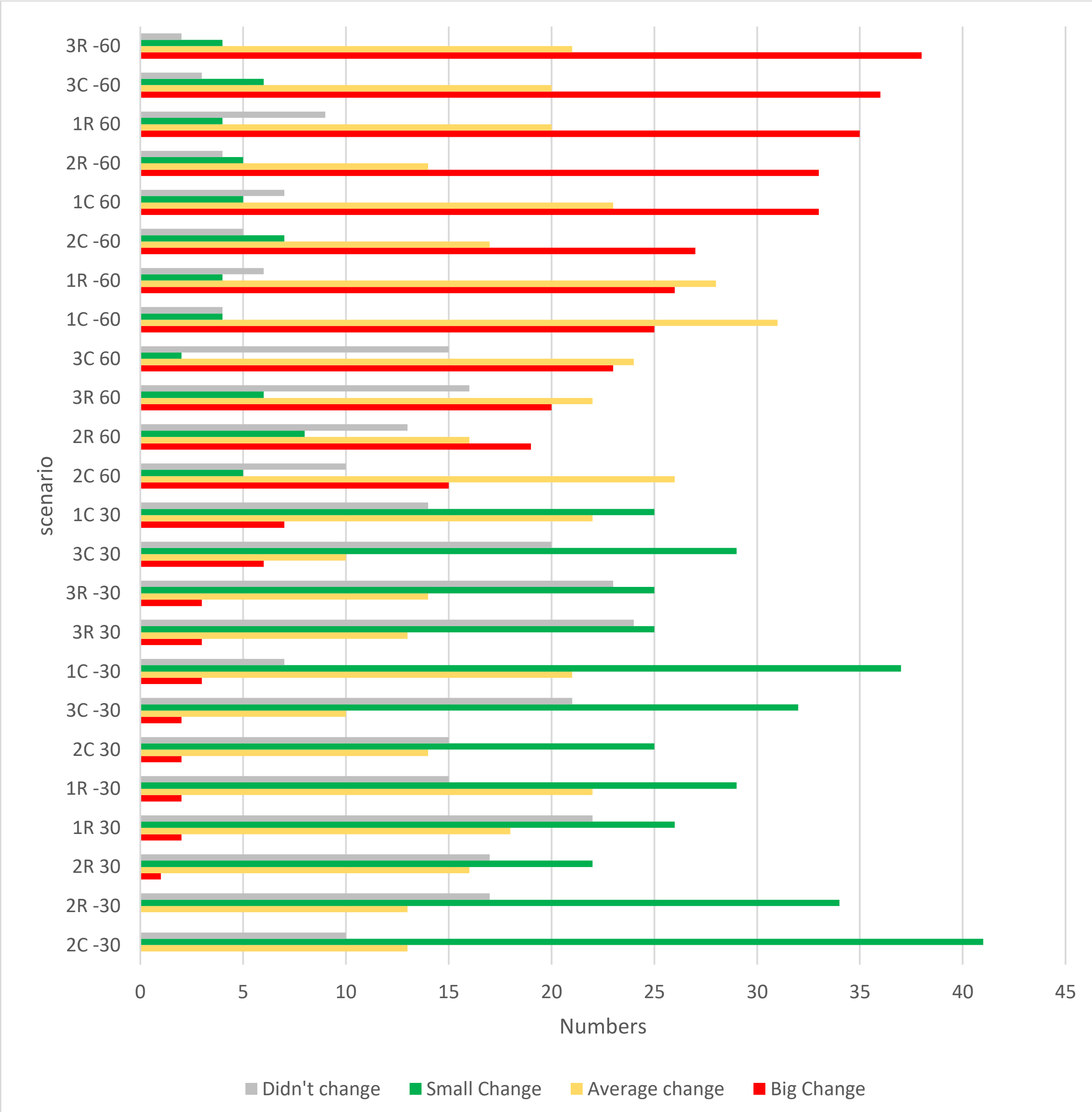


Figure 48: Histogram showing participant observations for each scenario

Another comparison between different speeds for each type was conducted. The comparison showed that there was no significant difference between all speeds. The last comparison was between the increasing and decreasing change in speed for the same speed of the countdown timer. In this case, also there was no significant difference between them.

Another general question was whether the participant thought this type of device would be useful even if there were a change in its speed: 72% agreed that it could be useful; only 8% did not agree. Which can be considered as a good indication of this type of devices. The more interesting question was about the level of acceptance of the speed changes: 40% accepted up to average speed change; 14% accepted even big changes in the speed. Most accepted all speed changes, which can be considered as more than a big change in our case. The last general question was if participants recommended using this type of countdown timer. More than 80% of them recommended to use the device; only 8% did not recommend its use. The participants who did not recommend this type of countdown timer generally recommended the regular type of countdown timers with digits and did not appear to understand the main concept behind using this type of countdown timer instead of the digits type. It was not easy to explain in the online version of the survey the concept of actuated versus fixed-time signals. It is sometimes even difficult to explain it on site, especially for people who do not have any idea about how traffic signals work. **Table 65** shows the participants answers regarding general questions after watching the videos.

Table 65: Participant answers regarding general questions after video scenarios

Which shape can be easier to estimate the remaining time				
Bar Countdown Timer				165 (65%)
Circular Countdown Timer				43 (17%)
Both are same				45 (18%)
Do you think that this device is useful even if there is a change in the speed				
1	**2**	**3**	**4**	**5**
14 (6%)	6 (2%)	51 (20%)	78 (31%)	104 (41%)
Do you recommend this type of countdown timers				
1	**2**	**3**	**4**	**5**
13 (5%)	7 (3%)	28 (11%)	66 (26%)	139 (55%)
Up to which level the speed change is acceptable				
Small change				80 (32%)
Average Change				102 (40%)
Big change				36 (14%)
All speed changes are accepted				35 (14%)

6.3. Defining an acceptance level

An acceptance level can be defined and derived from participant answers on the scenarios and the subsequent questions. The first step was to convert answers into numerical form by using a coding system. To accomplish this, all answers with small change were multiplied by 1; answers with average change were multiplied by 2, and answers with big change were multiplied by 3. In this case, each scenario received a rating out of three. **Table 66** shows the rates for each scenario. It can be noticed that the 30% speed changes rated between 1.24 to 1.67 for both shapes, and the 60% speed change scenarios rated between 2.22 to 2.56.

Table 66: Cumulative rates for each scenario

slow	normal	fast	slow	normal	fast	slow	normal	fast	slow	normal	fast
					Circular shape						
30	**30**	**30**	**-30**	**-30**	**-30**	**60**	**60**	**60**	**-60**	**-60**	**-60**
1.67	1.53	1.39	1.44	1.32	1.24	2.46	2.43	2.22	2.35	2.48	2.39
					Rectangular shape						
30	**30**	**30**	**-30**	**-30**	**-30**	**60**	**60**	**60**	**-60**	**-60**	**-60**
1.41	1.46	1.43	1.49	1.48	1.28	2.53	2.29	2.26	2.38	2.54	2.56

Table 67: Participant observation for 30% and 60% speed change and its multiplication with the corresponding factor

	Factor						**30% speed change**							**Total**
Big change	**3**	7	3	2	2	2	0	1	0	6	2	3	3	**31**
Average change	**2**	22	21	18	22	14	13	16	13	10	10	13	14	**186**
Small change	**1**	25	37	26	29	25	41	22	34	29	32	25	25	**350**
Didn't change	**0**	14	7	22	15	15	10	17	17	20	21	24	23	**205**
Total														**772**
	Factor						**60% speed change**							
Big change	**3**	33	25	35	26	15	27	19	33	23	36	20	38	**330**
Average change	**2**	23	31	20	28	26	17	16	14	24	20	22	21	**262**
Small change	**1**	5	4	4	4	5	7	8	5	2	6	6	4	**60**
Didn't change	**0**	7	4	9	6	10	5	13	4	15	3	16	2	**94**
Total														**746**

All shapes, speeds, and speed changes did not show significant differences between them. Because of this, all 30% speed changes for both shapes and in both directions, increasing and decreasing speed, can be combined. A participant answer of "didn't change" also will be considered because it represents the real-life situation. Some of those answers are real especially if it was related to 30% speed change. Some participants were not able to observe the change. Some other answers were likely chosen because the participant was not looking at the video at the time of the change. This can happen also in real life. The factor for this answer was chosen to be zero. **Table 67** shows the total number of each answer for each scenario.

Figure 49 shows the data plotted where the speed change is Y-axis, and the rating is X-axis. By plotting the trend line for the data using the linear, logarithmic, and exponential equations, it was shown that all trend lines have a problem with zero value. As the zero value was chosen to represent a no change situation, and the graph shows that at zero the value of the speed change is somewhere between 30% and 40%, the resulting plot is not logical. In addition to that, the problem occurs at the max rating as well, where the rating of 3 was somewhere between 50% and 60%.

In the second trial, the axis was swapped where speed change was chosen to be the X-axis and the rating to be the Y-axis. **Figure 50** shows the data plotted on the swapped axes. Two trend lines have been drawn: linear and logarithmic. The linear trend line had two problems, the initial rate value and the maximum rate value. The zero value shows precisely at almost zero. This is not logical because in the survey data some participants even with 30% speed change were not able to observe the changes. Which means there are some speed changes where no one can observe them even if it is bigger than 0%. On the other side, the logarithmic trend line shows the zero value at around 15% speed change. To make sure that this value is real, some additional scenarios with different speeds and 15% speed changes in both directions have been created and tested on focus groups where all of them could not notice any speed change. The other problem with linear trend line regarded the max rate, where it shows to be at around 85% speed change, and the logarithmic trend line was showing around 105%. As it has been stated that there are some changes which are not observed even if they are very big changes, the max value can yield a bit more than the linear relation. This can be better represented in the logarithmic trend line.

The next important question was: What is the acceptable rate for the speed changes? The answer to this question can be derived from the participants' answers to the question related to an acceptable level. The same rating was given for all answers except for the answer which stated that they accept all changes. That answer means that the participant accepted all speed changes including big changes. Moreover, it could potentially include even bigger changes than the big change in the survey but at the least would include the "big change" of this survey representing the 60% change. Based on that, the same rating has been given to this answer, which is 3.

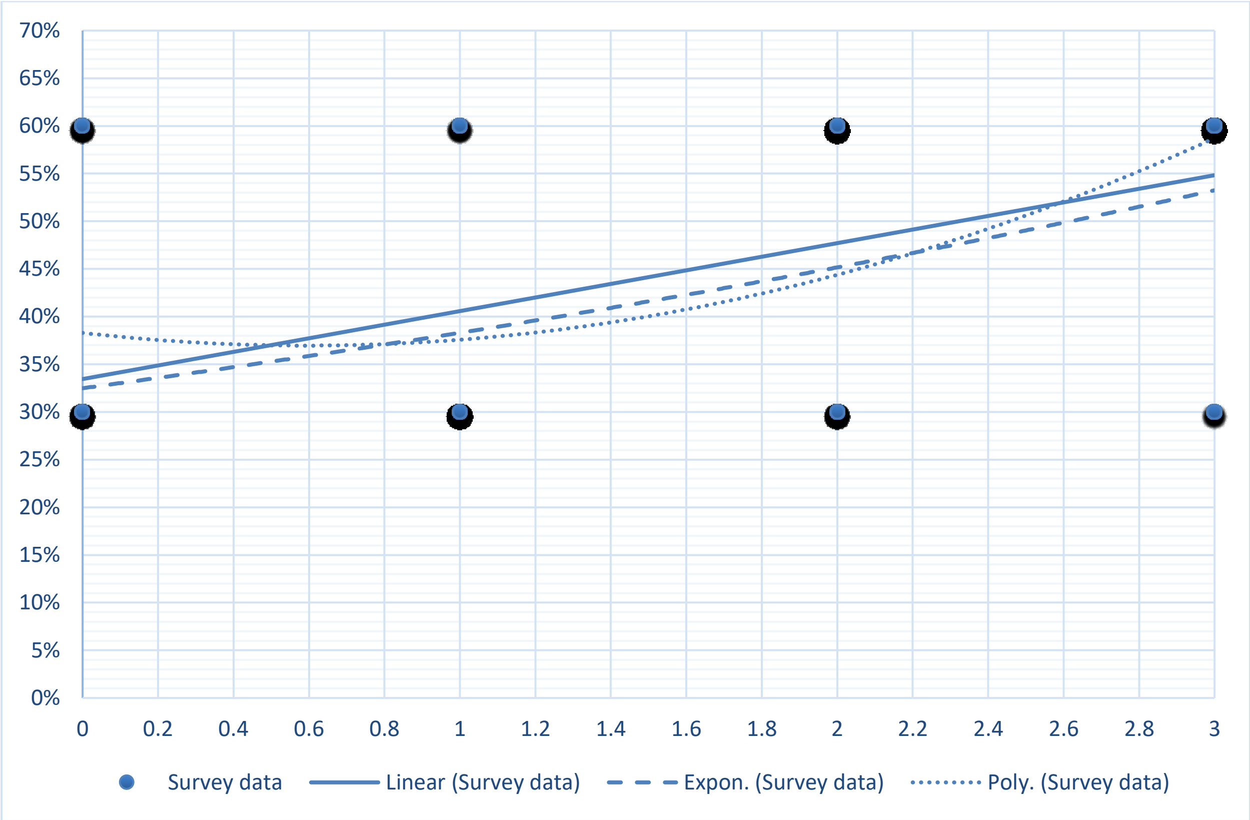


Figure 49: Trend lines with speed changes on Y-axis and rates on the X-axis

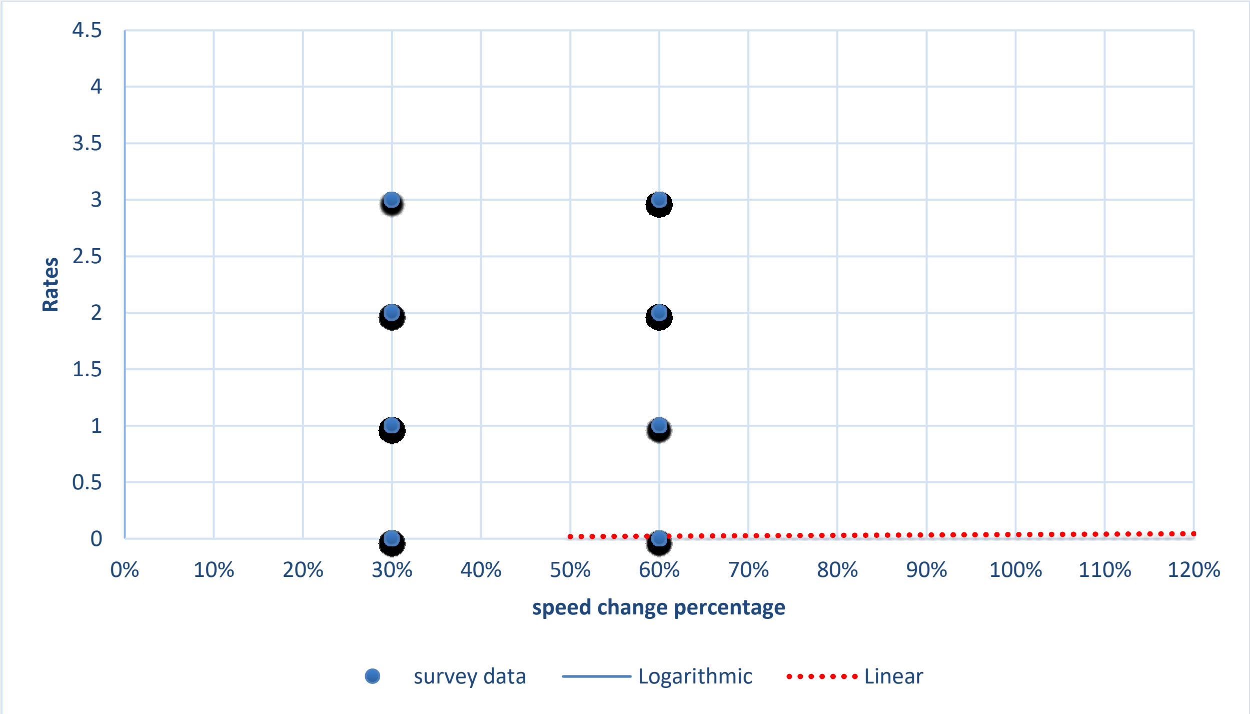


Figure 50: Trend lines with speed changes on X-axis and rates on the Y-axis

Table 68: Participant level of acceptance

Up to which level the speed change is acceptable	Factor (F)	Numbers (N)	F x N
Small change	1	80	80
Average Change	2	102	204
Big Change	3	36	108
All speed changes are accepted	3	35	105
Total		**253**	**497**

In this case, the accepted value can be calculated as:

$$Ar = \frac{\sum Fi * Ni}{\sum \mathrm{Ni}} \quad \textbf{Equation 11}$$

$$Ar = \frac{497}{253}$$

= 1.96

Where:

Ar Accepted rate

Fi Factor

Ni Total number

So, it can be concluded that the rating 1.96 is the acceptable rating for the speed changes. By going back to the **Figure 50,** the value 1.96 represents around 55% speed change. This could be the accepted value for the speed change in this type of countdown timer.

6.4. Evaluating the case study based on the evaluation method

In the previous chapter, a simple prediction method was used to check the performance of a countdown timer under a simulation environment taking real data from the field. Conditions for applying the result of the evaluation of that method on the case study need to be well defined. Two values have been obtained from the evaluation method, the rate of 1.96 and the acceptable speed change at 55%. The rate used to get the speed change will be vital for evaluating the countdown timer in the case study. The speed changes have been calculated for each time it accrues. Comparing the average speed changes with the accepted speed change could be one of the options for evaluating the case study. From the simulation results for the three different approaches (Major approach after the signalised junction, Major approach after free flow, and Minor approach) the average speed changes were 28%, 35%, and 35%, respectively. Comparing these numbers with the accepted speed changes could give an indication that all approaches' performances are accepted 100%. This method can be confusing and misleading. Taking the average of the whole period will not show the best and worst performance period. It is going to mix up all speed changes, and the details will not be clear.

Another way of checking the performance of the prediction method is to take the average of speed changes in each cycle time then check how many times the average falls below the accepted speed change level. This method shows the Major approach after the signalised junction, Major approach after free flow, and Minor approach obtained 96%, 83%, and 87%, respectively. This method could prove more realistic than the previous method. The most accurate method might be to take exactly how many times speed changes occurred in the total period. This could give the best performance measure. By applying this latter method results show 89%, 82%, and 82%, respectively as the accepted performance levels. The case study used a simple prediction method just for a trial basis. Most of the traffic signal systems use a well-designed prediction method which reflects positively on countdown timer performance.

7. Summary and recommendations

Traffic signals have been improved many times since their invention and initial use. A modern improvement is to add timers indicating the remaining time left on signal intervals. The primary purpose of such timer displays is to improve the safety and efficiency of traffic signals.

For pretimed signals (fixed time), remaining interval times are predictable and can be displayed easily. At traffic-responsive signals, however, traffic counters and remaining red or green times must be revisited. The initial timer display devices had been constrained to work with only fixed-time signal controls, which often are less efficient compared to actuated signals. Therefore, some cities which were installing traffic-responsive signals had removed devices that were designed to display remaining times only for fixed-time signals. This study investigated methods and perceptions regarding timers that could be used at actuated traffic signal intersections.

A literature review uncovered multiple studies showing mixed impacts of signal countdown timers. Regarding vehicle countdown timers during green intervals, existing studies showed a slightly positive influence on delay and discharged at intersections but a negative influence on safety. On the other hand, studies indicated vehicle countdown timers during red intervals showed a positive influence on both safety and start-up time. In the case of pedestrian countdown timers, most study results showed a positive influence for both red and green interval timers. On the user preference side, most of the studies showed that the majority of pedestrians and drivers like having signal countdown timer displays because they reduce frustration while waiting in a queue or waiting to cross an intersection. User preferences also noted a perceived increase in safety. Based on the results from the studies covered in the literature review chapter, a device with red countdown timer display has been recommended.

By looking at the benefits and advantages of countdown timers at the same time the constraint of working under fixed time signal control beside the preference of the actuated traffic signals, the primary goal of this research was to solve this problem by developing a presentation method for actuated traffic signal countdown timers with a performance measure to evaluate the method. Also, the study investigated public opinion in the United Arab Emirates toward the use of signal countdown timers. In order to achieve project goals, two questionnaires were prepared. One questionnaire assessed the perception of drivers toward vehicle countdown timers. The second questionnaire assessed pedestrian perception toward pedestrian countdown timers. A total of 1,000 valid questionnaires were collected in May 2015, 500 from drivers and 500 from pedestrians. Statistical analysis studied the influence of characteristics of the respondents on their perceptions toward the timer displays. Analysis showed that both drivers and pedestrians generally perceived countdown timers positively.

An algorithm was developed to use a prediction method and change the speed of countdown timers to suit the phase duration for signals in actuated mode. This algorithm has been tested in a simulated environment using the microsimulation software VISSIM in three different traffic demand scenarios to check the prediction performance. A simple method of red interval prediction was proposed for signals running under actuated mode to evaluate the performance of the countdown timer algorithm. Not surprisingly, the simulation's results indicated the best prediction quality occurred during peak periods because that is the period when green times are usually maximised. Countdown timers with digits were not considered applicable in the case of actuated signals because the timing was not fixed, so the timer design used in this research was a bar-and-circular type.

As a final step in the study, a method was developed to evaluate the technology introduced in the project and to define an acceptance tolerance. Change in speed was the key to defining the evaluation method. To outline acceptable speed changes, a questionnaire was prepared which included videos showing countdown timers with different speed changes. Online surveys were distributed through email to random groups including some specialists in the field of traffic control. A total sample of 363 responses was collected. Of those, 253 responses have been validated and analysed to define the accepted speed change. Questionnaire results, in general, showed that the characteristics of participants did not affect their observations and perceptions. The findings were converted to the numerical format, and the results showed that a 55% speed change could be acceptable for these types of countdown timers used with actuated signals. The acceptance tolerance has been applied to a case study (described in Chapter 6), which found that 89%, 82%, and 82%, respectively, were the accepted performance levels for three scenarios: Major approach after the signalised junction, Major approach after free flow, and Minor approach. The case study used a simple prediction method for a trial basis. Most of the traffic signal systems use well-designed prediction methods which could reflect positively on countdown timer performance. Getting performance result above 80% by using a simple prediction method can be a positive indication that the method is working correctly. The acceptance level can be increased by using an advanced method of time prediction. By stating that, it can be concluded that the countdown timer has no more constraint with actuated traffic signal. By using this method, a countdown timer can be used at junction working under actuated mode.

All benefits and advantages of countdown timer can be added as a feature in the advanced controller modes and vehicles using C2I technology.

Future work

One of the main difficulty in this study was that the countdown technology is not yet used in most intersections with actuated signalisation. Based on that, further studies of countdown timer use and enhancements in the proposed algorithm are recommended:

A study based on a simulation model could be more efficient if participant observations can be taken from real devices currently in use. In this study, the acceptance level for the speed change was calculated based on a single case study.

One recommendation for enhancement could be to apply the evaluation method on a complex prediction algorithm to check the performance of the countdown timer. In the case study developed for this project, a simple prediction method was used to predict the remaining red time.

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Appendix A – SCT questionnaire forms

May 2015

Drivers opinion about the countdown timers in UAE

A. Zone: ....

B. Resident status: ☐ Local ☐ Resident ☐ Tourist

C. Gender: ☐ Male ☐ Female

D. Age group: ☐ 18-24 ☐ 25-34 ☐ 35-44 ☐ 45-54 ☐ >55

E. Do you have an idea about the signal's countdown timers as above?

☐ Yes ☐ No

F. How many car trips you have in a day:

☐ <1 ☐ 1-2 ☐ 3-4 ☐ >5

---

1. Relieve frustration from stopping for long and uncertain amount of time during the red phase.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

2. Better use of waiting time spent during the red phase.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

3. Turn off the engine while waiting in the queue.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

4. Assist to promptly proceed through the intersection when the signal turns green.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

5. Assist better judgment to stop when the signal turns red.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

6. Ensure confidence in driving thru intersection during the green phase.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ Don't Know

Any further comments related to the topic:

....

....

....

Thank you for your participation

Contact Number: ....

May 2015

Pedestrian's opinion about countdown timers in UAE

A. Zone: ....

B. Resident status: 1 ☐ Local 2 ☐ Resident. Nationality .... 3 ☐ Tourist. Nationality ....

C. Gender: 1 ☐ Male 2 ☐ Female

D. Age group: 1 ☐ 18-24 2 ☐ 25-34 3 ☐ 35-44 4 ☐ 45-54 5 ☐ >55

E. Do you have an idea about the pedestrian's signal countdown timers as shown here?

1 ☐ Yes 2 ☐ No

F. How many times you are crossing pedestrian's signal in a week:

1 ☐ <1 2 ☐ 1-3 3 ☐ 4-6 4 ☐ >6

---

1. Will you prefer a pedestrian signal countdown device?

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ 6 Don't Know

2. Do you think that pedestrian crossing with signal countdown devices are safer?

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ 6 Don't Know

3. Do you think that you will not cross the red light if you know the remaining time?

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ 6 Don't Know

4. Relieve frustration from stopping for long and uncertain amount of time during the red phase.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ 6 Don't Know

5. Assist better judgment to move faster or slower depending on the time remaining.

☐ 1 (Agree) ☐ 2 ☐ 3 ☐ 4 ☐ 5 (Disagree) ☐ 6 Don't Know

Any further comments related to the topic:

....

....

....

Thank you for your participation

Contact Number: ....

Appendix B – Example for how to calculate a Chi Square Statistic Test

Step1: Calculating expected value

	Observed (O)			Expected (E)	
	Male (A)	**Female (B)**	**Sum (C)**	**Male (M)**	**Female (F)**
(1) St agree	134	72	**206**	$\frac{C1 * AD}{CD}$	$\frac{C1 * BD}{CD}$
(2) Agree	123	82	**205**	$\frac{C2 * AD}{CD}$	$\frac{C2 * BD}{CD}$
(3) Neutral	39	21	**60**	$\frac{C3 * AD}{CD}$	$\frac{C3 * BD}{CD}$
(4) Don't agree	10	6	**16**	$\frac{C4 * AD}{CD}$	$\frac{C4 * BD}{CD}$
(5) St don't agree	1	2	**3**	$\frac{C5 * AD}{CD}$	$\frac{C5 * BD}{CD}$
(6) Don't know	5	5	**10**	$\frac{C6 * AD}{CD}$	$\frac{C6 * BD}{CD}$
Sum (D)	**312**	**188**	**500**		

Step2: Calculating Chi squared value

(O)	(E)	O - E	$(O - E)^2$	$(O - E)^2/E$
134	128.5	5.50	30.25	0.24
123	127.9	-4.90	24.01	0.19
39	37.4	1.60	2.56	0.07
10	10.0	0.00	0.00	0.00
1	1.9	-0.90	0.81	0.43
5	6.2	-1.20	1.44	0.23
72	77.5	-5.50	30.25	0.39
82	77.1	4.90	24.01	0.31
21	22.6	-1.60	2.56	0.11
6	6.0	0.00	0.00	0.00
2	1.1	0.90	0.81	0.74
5	3.8	1.20	1.44	0.38
			Total	**3.08**

From the Chi square table for $x^2 = 3.08$ and degree of freedom 5, ρ=0.7 which means there no significant difference between males and females regarding this question.

Appendix C – VISVAP code for Al Nakhi signalized intersection

```
VAP_FREQUENCY 1;

CONST
        MinG1 = 5,
        MinG2 = 5,
        MinG3 = 5,
        MinG4 = 5,
        HD = 3,
        Am = 3,
        AR = 3;

/* ARRAYS */

/* SUBROUTINES */

/* PARAMETERS DEPENDENT ON SCJ-PROGRAM */
        IF( prog_aktiv = 1 ) AND ( prog_aktiv0vv <> 1 ) THEN
          prog_aktiv0vv := 1;
          MaxG3 := 20;
          MaxG4 := 15;
          MaxG1 := 15;
          MaxG2 := 15;
        ELSE IF( prog_aktiv = 2 ) AND ( prog_aktiv0vv <> 2 ) THEN
          prog_aktiv0vv := 2;
          MaxG3 := 53;
          MaxG4 := 29;
          MaxG1 := 25;
          MaxG2 := 25;
        ELSE IF( prog_aktiv = 3 ) AND ( prog_aktiv0vv <> 3 ) THEN
          prog_aktiv0vv := 3;
          MaxG3 := 30;
          MaxG4 := 30;
          MaxG1 := 20;
          MaxG2 := 20;
        ELSE IF( prog_aktiv = 4 ) AND ( prog_aktiv0vv <> 4 ) THEN
          prog_aktiv0vv := 4;
          MaxG3 := 40;
          MaxG4 := 40;
          MaxG1 := 20;
          MaxG2 := 30;
        ELSE IF( prog_aktiv = 5 ) AND ( prog_aktiv0vv <> 5 ) THEN
          prog_aktiv0vv := 5;
          MaxG3 := 33;
          MaxG4 := 40;
          MaxG1 := 20;
          MaxG2 := 22;
```

```
        ELSE IF( prog_aktiv = 6 ) AND ( prog_aktiv0vv <> 6 ) THEN
          prog_aktiv0vv := 6;
          MaxG3 := 30;
          MaxG4 := 55;
          MaxG1 := 15;
          MaxG2 := 22;
        ELSE IF( prog_aktiv = 7 ) AND ( prog_aktiv0vv <> 7 ) THEN
          prog_aktiv0vv := 7;
          MaxG3 := 27;
          MaxG4 := 35;
          MaxG1 := 15;
          MaxG2 := 25;
        END END END END END END END;

/* EXPRESSIONS */
        MaxR1 := G2 + G3 + G4 + (4*AR) + (3*AM);

/* MAIN PROGRAM */

S00Z001:   SF1 := SF1/100 ; SF2 := SF2/100 ; SF3 := SF3 / 100;
S00Z002:   Start (timer);
S00Z003:   IF Cst( 1 , green) =1 THEN
S01Z003:     IF timer > 3600 THEN
S02Z003:       IF timer > 8100 THEN
S03Z003:         IF timer > 22500 THEN
S04Z003:           IF timer > 33300 THEN
S05Z003:             IF timer > 44100 THEN
S06Z003:               IF timer > 53100 THEN
S07Z003:                 Set_Prog (7);
S09Z006:                 IF G2 > MaxG2 THEN
S10Z006:                   G2 := MaxG2;
S11Z006:                   IF G3 > MaxG3 THEN
S12Z006:                     G3 := MaxG3;
S13Z006:                     IF G4 > MaxG4 THEN
S14Z006:                       G4 := MaxG4;
S09Z015:                       RC1 := 0 ; S := 0;
S10Z015:                       IF NOT (Tg( 1 ) <= MinG1) THEN
S10Z016:                         IF Headway( 6 ) > HD THEN
S12Z016:                           AG1 := Tg (1);
S13Z016:                           Ssgd( 1 , amber)
                                ELSE
S10Z017:                           IF Tg(1) >= MaxG1 THEN
S12Z017:                             AG1 := Tg (1);
S13Z017:                             Ssgd( 1 , amber)
                                  END
                                END
                              END
                            ELSE
                              GOTO S09Z015
```

```
                    END
                  ELSE
S11Z007:                 IF G4 > MaxG4 THEN
S12Z007:                   G4 := MaxG4;
                      GOTO S09Z015
                    ELSE
                      GOTO S09Z015
                    END
                  END
                ELSE
S09Z007:               IF G3 > MaxG3 THEN
S10Z007:                 G3 := MaxG3;
                    GOTO S11Z007
                  ELSE
S09Z008:                 IF G4 > MaxG4 THEN
S10Z008:                   G4 := MaxG4;
                      GOTO S09Z015
                    ELSE
                      GOTO S09Z015
                    END
                  END
                END
              ELSE
S06Z004:           Set_Prog (6);
                GOTO S09Z006
              END
            ELSE
S05Z004:         Set_Prog (5);
              GOTO S09Z006
            END
          ELSE
S04Z004:       Set_Prog (4);
            GOTO S09Z006
          END
        ELSE
S03Z004:     Set_Prog (3);
          GOTO S09Z006
        END
      ELSE
S02Z004:   Set_Prog (2);
        GOTO S09Z006
      END
    ELSE
S01Z004: Set_Prog (1);
      GOTO S09Z015
    END
  END;
S00Z020:  IF Cst (1, amber) =1 THEN
S10Z020:    IF Ts (1) >=Am THEN
```

```
S12Z020:      RC1 := 100 ; C := 0; RecVal( 1 , G1) ; RecVal( 2 , G2) ; RecVal( 3 , G3) ; RecVal( 4 , G4); RecVal( 9 ,
CT); RecVal (10 , RT);
S13Z020:       Ssgd( 1 , red);
S17Z020:       R1 := 1
           END
         END;
S00Z022:   IF (Cst (1 , red) =1) and (Cst (2 , red) =1) and (Cst (3 , red) =1) and (Cst (4 , red) =1) THEN
S01Z022:     IF R1 =1 THEN
S03Z022:       C := C+1 ; RC1 := (MaxR1 - C ) * 100 / MaxR1;
S04Z022:       IF Tr(1) >= AR THEN
S13Z022:         Ssgd( 2 , green);
S17Z022:         R1 := 0
             END
           ELSE
S01Z023:       IF L1 = 1 THEN
S06Z023:         C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S07Z023:         IF Tr(2) >= AR THEN
S13Z023:           Ssgd( 3 , green);
S17Z023:           L1 := 0
               END
             ELSE
S01Z024:         IF U1 = 1 THEN
S06Z024:           C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S08Z024:           IF Tr(3) >= AR THEN
S13Z024:             Ssgd( 4 , green);
S17Z024:             U1 := 0
                 END
               ELSE
S01Z025:           IF D1 = 1 THEN
S06Z025:             C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S09Z025:             IF Tr(4) >= AR THEN
S10Z025:               G1 := AG1 ; G2 := AG2 ; G3 := AG3 ; G4 := AG4 ; CT := G1 + G2 + G3 + G4 + 4*(AR + Am);
RT := CT - G1 - Am;
S11Z025:               RecVal( 1 , AG1) ; RecVal( 2 , AG2) ; RecVal( 3 , AG3) ; RecVal( 4 , AG4);
S13Z025:               Ssgd(1 , green);
S17Z025:               D1 := 0
                   END
                 END
               END
             END
           END
         END;
S00Z027:   IF Cst( 2 , green) =1 THEN
S10Z027:     IF Tg( 2 ) <= MinG2 THEN
S12Z027:       C := C+1 ; RC1 := (MaxR1 - C ) * 100 / MaxR1
           ELSE
S10Z028:       IF Tg (2) >= G2 THEN
S12Z028:         S := (G3+Ar+Am) / (MaxG2-G2+G3+Ar+Am) ; C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S14Z028:         IF Headway( 7 ) > HD THEN
```

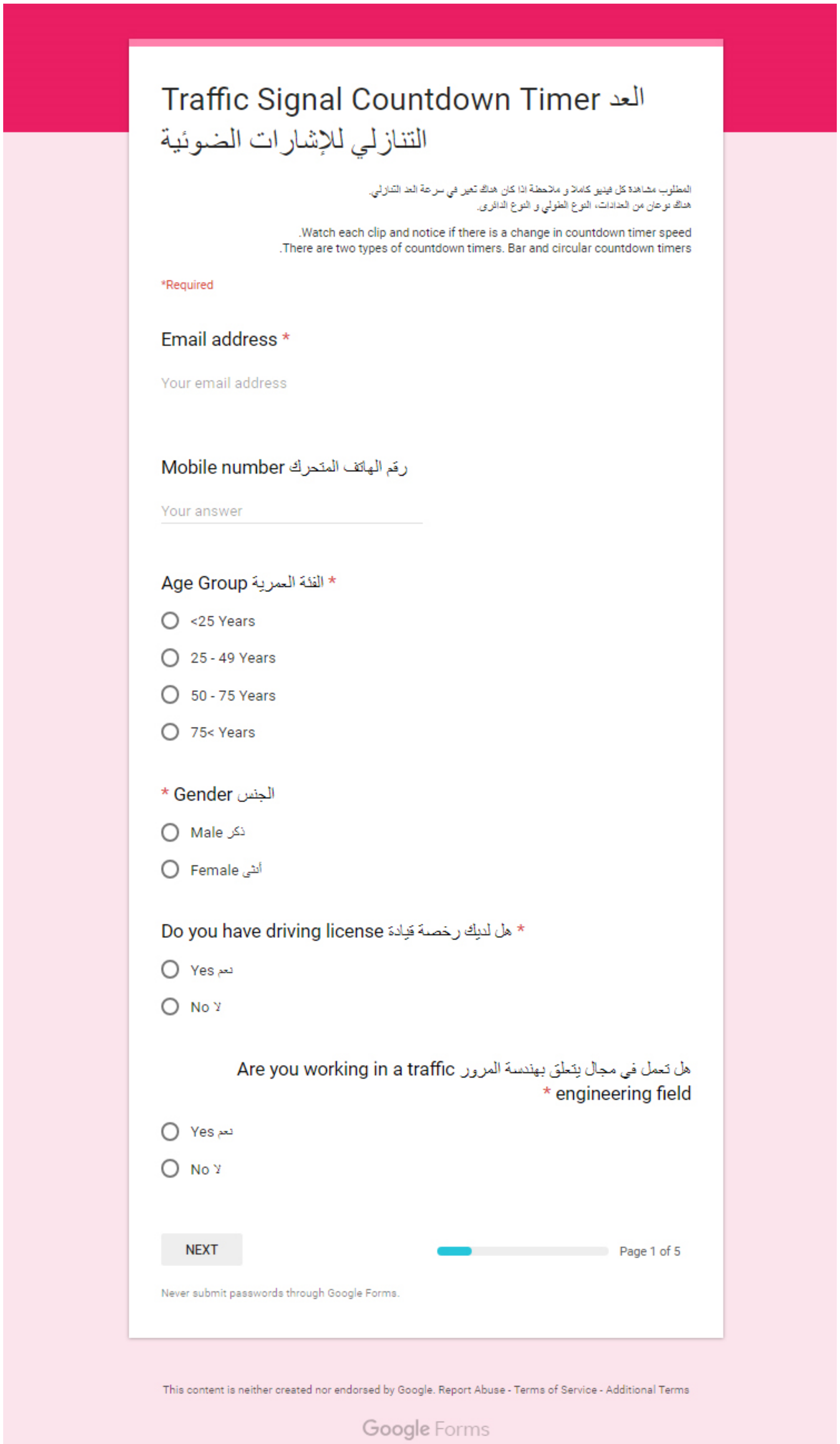
```
S15Z028:          S := 1-(((Tg(2)-G2)-((1-S)*(Tg(2)-G2)))/(G3+Ar+Am));
S16Z028:          AG2 := Tg (2);
S17Z028:          Ssgd( 2 , amber)
           ELSE
S14Z029:          IF Tg(2) >= MaxG2 THEN
S16Z029:            AG2 := Tg (2);
S17Z029:            Ssgd( 2 , amber)
             END
           END
         ELSE
S10Z030:        IF Headway( 7 ) > HD THEN
S12Z030:          C := C+1 ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S15Z030:          S := 1 + ((G2-Tg(2))/(G3+Ar+Am));
S16Z030:          AG2 := Tg (2);
S17Z030:          Ssgd( 2 , amber)
           ELSE
S10Z031:          C := C+1 ; RC1 := (MaxR1 - C ) * 100 / MaxR1
           END
         END
       END
     END;
S00Z033:   IF Cst (2, amber) =1 THEN
S07Z033:     C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S10Z033:     IF Ts (2) >=Am THEN
S16Z033:       Ssgd( 2 , red);
S17Z033:       L1 := 1
       END
     END;
S00Z035:   IF Cst( 3 , green) =1 THEN
S10Z035:     IF Tg( 3 ) <= MinG3 THEN
S13Z035:       C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1
       ELSE
S10Z036:       IF Tg (3) >= G3 THEN
S12Z036:         S := (G4+Ar+Am) / (MaxG3-G3+G4+Ar+Am) ; C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S14Z036:         IF Headway( 8 ) > HD THEN
S15Z036:          S := 1-(((Tg(3)-G3)-((1-S)*(Tg(3)-G3)))/(G4+Ar+Am));
S16Z036:          AG3 := Tg (3);
S17Z036:          Ssgd( 3 , amber)
           ELSE
S14Z037:          IF Tg(3) >= MaxG3 THEN
S16Z037:            AG3 := Tg (3);
S17Z037:            Ssgd( 3 , amber)
             END
           END
         ELSE
S10Z038:        IF Headway( 8 ) > HD THEN
S11Z038:          IF AG2 > G2 THEN
S12Z038:            C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S15Z038:            S := 1+((G3-Tg(3)-((1-S)*(G3-Tg(3))))/(G4+Ar+Am));
```

```
S16Z038:            AG3 := Tg (3);
S17Z038:            Ssgd( 3 , amber)
                ELSE
S12Z039:            C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S15Z039:            S := 1+((((S-1)*(G3-Tg(3)))+G3-Tg(3))/(G4+Am+Ar));
S16Z039:            AG3 := Tg (3);
S17Z039:            Ssgd( 3 , amber)
                END
              ELSE
S10Z040:          C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1
              END
            END
          END
        END;
S00Z042:   IF Cst (3, amber) =1 THEN
S07Z042:     C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S10Z042:     IF Ts (3) >=Am THEN
S13Z042:       Ssgd( 3 , red);
S17Z042:       U1 := 1
          END
        END;
S00Z044:   IF Cst( 4 , green) =1 THEN
S10Z044:     IF Tg(4 ) <= MinG4 THEN
S13Z044:       C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1
          ELSE
S10Z045:       IF Tg (4) >= G4 THEN
S12Z045:         S := (Ar+Am) / (MaxG4-G4+Ar+Am) ; C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S14Z045:         IF Headway( 9 ) > HD THEN
S15Z045:           S := 1-(((Tg(4)-G4)-((1-S)*(Tg(4)-G4)))/(Ar+Am));
S16Z045:           AG4 := Tg (4);
S17Z045:           Ssgd( 4 , amber)
              ELSE
S14Z046:           IF Tg(4) >= MaxG4 THEN
S16Z046:             AG4 := Tg (4);
S17Z046:             Ssgd( 4 , amber)
                END
              END
            ELSE
S10Z047:         IF Headway( 9 ) > HD THEN
S11Z047:           IF AG3 > G3 THEN
S12Z047:             C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S15Z047:             S := 1+((G4-Tg(4)-((1-S)*(G4-Tg(4))))/(Ar+Am));
S16Z047:             AG4 := Tg (4);
S17Z047:             Ssgd( 4 , amber)
                ELSE
S12Z048:             C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S15Z048:             S := 1+((((S-1)*(G4-Tg(4)))+G4-Tg(4))/(Am+Ar));
S16Z048:             AG4 := Tg (4);
S17Z048:             Ssgd( 4 , amber)
```

```
              END
            ELSE
S10Z049:          C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1
            END
          END
        END
      END;
S00Z051:   IF Cst (4, amber) =1 THEN
S07Z051:     C := C+S ; RC1 := (MaxR1 - C) * 100 / MaxR1;
S10Z051:     IF Ts (4) >=Am THEN
S13Z051:       Ssgd( 4 , red);
S17Z051:       D1 := 1
        END
      END;
S00Z053:    tg2 := Tg(2); tg3 := Tg(3); tg4 := Tg(4); tr1 := Tr(1); tr2 := Tr(2); tr3 := Tr(3); tr4 := Tr(4); ts1 :=
Ts(1); ts2 := Ts(2); ts3 := Ts(3); ts4 := Ts(4);
S00Z054:   S := S*100 ; C := C*100;
S00Z055:   RC1 := RC1 * 100 ; RecVal(5 , RC1) ; RC1 := RC1 / 100;
S00Z056:   RecVal(11 , Tg2); RecVal(12 , Tg3); RecVal(13 , Tg4); RecVal(14 , Tr1); RecVal(15 , Tr2); RecVal(16 ,
Tr3); RecVal(17 , Tr4); RecVal(18 , Ts1); RecVal(19 , Ts2); RecVal(20 , Ts3); RecVal(21 , Ts4);
S00Z057:   RecVal( 6 , S) ; RecVal( 7 , timer) ; RecVal( 8 , C) ; C := C / 100 ; S := S / 100
PROG_ENDE:    .
/*---------------------------------------------------------------------------*/
```

Appendix D – Online questionnaire testing human response on SCT presentation

Section 1



Traffic Signal Countdown Timer العد التنازلي للإشارات الضوئية

المطلوب مشاهدة كل فيديو كاملا و ملاحظة اذا كان هناك تغير في سرعة العد التنازلي.
هناك نوعان من العدادات، النوع الطولي و النوع الدائري.

.Watch each clip and notice if there is a change in countdown timer speed
.There are two types of countdown timers. Bar and circular countdown timers

*Required

Email address *

Your email address

Mobile number رقم الهاتف المتحرك

Your answer

Age Group الفئة العمرية *

- <25 Years
- 25 - 49 Years
- 50 - 75 Years
- 75< Years

* Gender الجنس

- Male ذكر
- Female أنثى

Do you have driving license هل لديك رخصة قيادة *

- Yes نعم
- No لا

Are you working in a traffic هل تعمل في مجال يتعلق بهندسة المرور
* engineering field

- Yes نعم
- No لا

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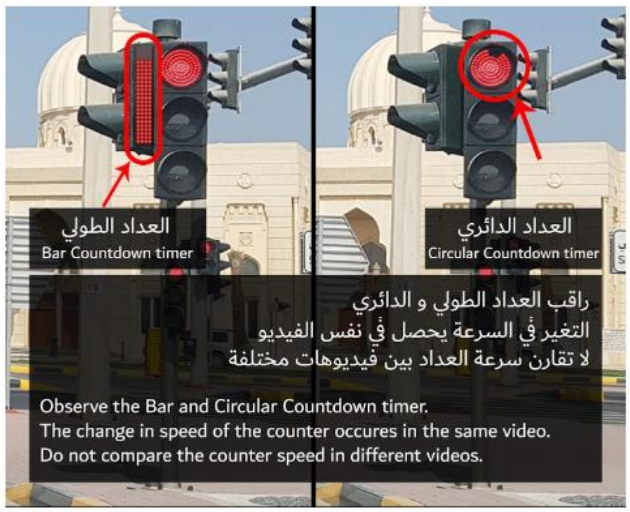
Section 2

Traffic Signal Countdown Timer العداد التنازلي للإشارات الضوئية

يرجى قراءة التعليمات قبل البدء بالإجابة Please read the instructions before you start answering



Watch this example before you start شاهد هذا المثال قبل البدء بالإجابة

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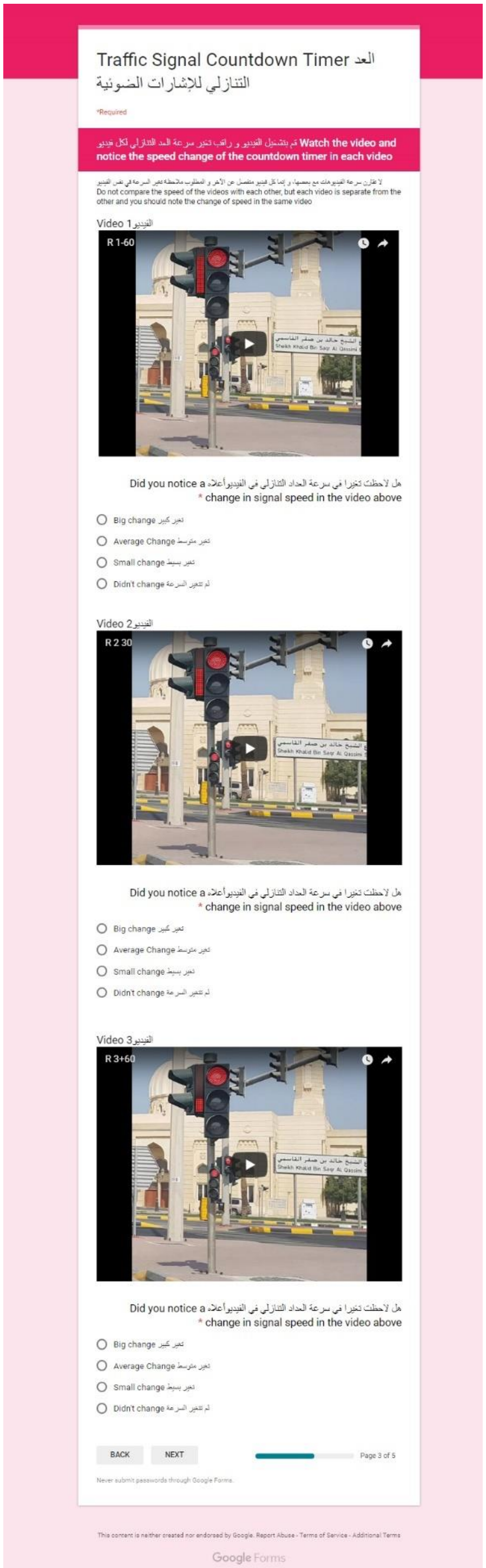
Section 3



Traffic Signal Countdown Timer العد التنازلي للإشارات الضوئية

*Required

قم بتشغيل الفيديو و راقب تغير سرعة العد التنازلي لكل فيديو Watch the video and notice the speed change of the countdown timer in each video

لا تقارن سرعة الفيديوهات مع بعضها، و إنما كل فيديو منفصل عن الآخر و المطلوب ملاحظة تغير السرعة في نفس الفيديو
Do not compare the speed of the videos with each other, but each video is separate from the other and you should note the change of speed in the same video

Video 1 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

Video 2 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

Video 3 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

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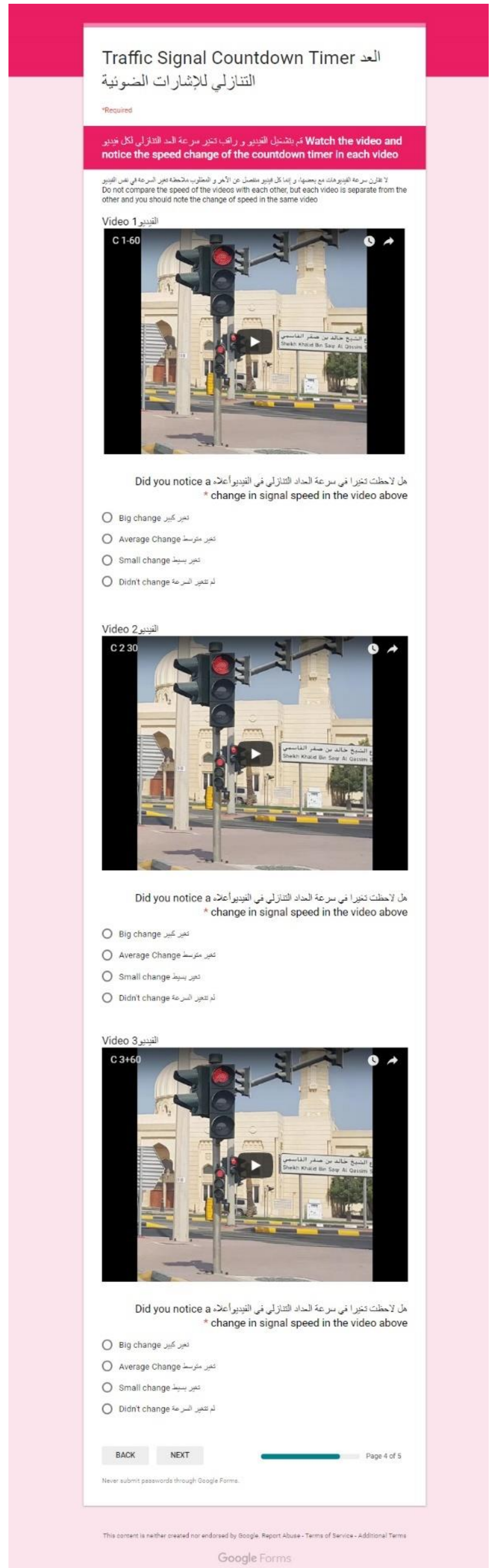
Section 4



Traffic Signal Countdown Timer العد التنازلي للإشارات الضوئية

*Required

قم بتشغيل الفيديو و راقب تغير سرعة العد التنازلي لكل فيديو Watch the video and notice the speed change of the countdown timer in each video

لا تقارن سرعة الفيديوهات مع بعضها، و إنما كل فيديو منفصل عن الآخر و المطلوب ملاحظة تغير السرعة في نفس الفيديو
Do not compare the speed of the videos with each other, but each video is separate from the other and you should note the change of speed in the same video

Video 1 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

Video 2 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

Video 3 الفيديو

هل لاحظت تغيرا في سرعة العداد التنازلي في الفيديوأعلاه Did you notice a change in signal speed in the video above *

- Big change تغير كبير
- Average Change تغير متوسط
- Small change تغير بسيط
- Didn't change لم تتغير السرعة

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Section 5

Traffic Signal Countdown Timer العداد التنازلي للإشارات الضوئية

*Required

General Questions أسئلة عامة

Which shape can be easier to estimate the remaining time *
أى الأشكال تعتقد بأنها الأسهل لمعرفة الوقت المتبقي

- ○ Bar Countdown Timer العداد الطولي
- ○ Circular Countdown timer العداد الدائري
- ○ Both are same لا يوجد فرق بينهما

Do you think هل تعتقد بأن هذه الأجهزة مفيدة حتى لو كان هناك تغير في سرعة العداد
* that this device is useful even if there is a change in the speed

	1	2	3	4	5	
Not غير مفيد useful	○	○	○	○	○	Very مفيد جدا Useful

Up to which level the speed إلى أي حد يعتبر التغير في سرعة العداد مقبولا
* change is acceptable

- ○ Big change تغير كبير
- ○ Average Change تغير متوسط
- ○ Small change تغير بسيط
- ○ All speed changes are accepted جميع التغيرات في السرعة مقبولة

Do you recommend هل تنصح باستخدام هذه العدادات الخاصة بالإشارات الضوئية
* this type of countdown timers

	1	2	3	4	5	
Don't لا أنصح recommend	○	○	○	○	○	Highly أنصح بشدة recommended

لإنجاح هذا البحث، نتمنى مشاركتك في الاستبيانات المكملة لهذا الاستبيان، فهل ترغب في
To ensure the success of this research, المشاركة في الاستبيانات القادمة؟
we hope your participation in questionnaires complementary to
this questionnaire, do you want to participate in the coming
* ?questionnaires

- ○ Yes نعم
- ○ No لا

Any Comments أي ملاحظات أخرى تود إضافتها

Your answer

Thank you for your participation شكرا لمشاركتك

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