# Transportation Research Record

## A detailed synthesis on the impact of smart device induced distraction on driver, saturation flow, and startup loss time

--Manuscript Draft--

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| **Full Title:** | A detailed synthesis on the impact of smart device induced distraction on driver, saturation flow, and startup loss time |
| **Abstract:** | The use of electronic device by drivers poses a significant safety risk; however, distractions appear likely to impact operations as well as safety. Distracted driving may cause a vehicle to travel at a lower than expected speed or fail to move when receiving the right-of-way. Failure to response immediately when the signal turns green may have an impact on start-up lost time. At the on-set of green, the perception-reaction time varies from time to time and place to place due to- distracted drivers, psychological factors and other circumstances. On the other hand, the ideal saturation flow rate is defined as the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing condition, assuming that the green signal is available at all times and no lost time are experienced. But ideally, many sorts of driver distraction impinge on driver and increases startup lost time. The delays at traffic signals contribute an estimated 5 to 10 percent of all traffic delay. In 2017, in the US alone, congestion cost about $305 billion. Electronic device distraction requires careful exploration to quantify any costs associated with the operational inefficiencies that it introduces. Unfortunately, very few studies have been done to understand the connection. This synthesis study focuses on the aforementioned factors and any state-of-the-art method for signalized intersection performance evaluation. The key directions for future research include investigating the factors that contribute to distractions at signalized intersections, the frequency of occurrence and the magnitude of impact. |
| **Manuscript Classifications:** | Administration and Management; Management and Productivity ABC20; Organizational Sustainability; Performance Management |
| **Manuscript Number:** | 20-05850 |
| **Article Type:** | Presentation and Publication |
| **Order of Authors:** | Jobaidul Alam Boni, M.Eng |

# A detailed synthesis on the impact of smart device induced distraction on driver, saturation flow, and startup loss time

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## Abstract

The use of electronic device by drivers poses a significant safety risk; however, distractions appear likely to impact operations as well as safety. Distracted driving may cause a vehicle to travel at a lower than expected speed or fail to move when receiving the right-of-way. Failure to response immediately when the signal turns green may have an impact on start-up lost time. At the on-set of green, the perception-reaction time varies from time to time and place to place due to- distracted drivers, psychological factors and other circumstances. On the other hand, the ideal saturation flow rate is defined as the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing condition, assuming that the green signal is available at all times and no lost time are experienced. But ideally, many sorts of driver distraction impinge on driver and increases startup lost time. The delays at traffic signals contribute an estimated 5 to 10 percent of all traffic delay. In 2017, in the US alone, congestion cost about $305 billion. Electronic device distraction requires careful exploration to quantify any costs associated with the operational inefficiencies that it introduces. Unfortunately, very few studies have been done to understand the connection. This synthesis study focuses on the aforementioned factors and any state-of-the-art method for signalized intersection performance evaluation. The key directions for future research include investigating the factors that contribute to distractions at signalized intersections, the frequency of occurrence and the magnitude of impact.


## Introduction

State and local agencies place and maintain traffic control devices at intersections to address roadway operations and safety. (FHWA, 2013). Properly installed and operated traffic signals play an important role in achieving optimal performance at an intersection by assigning vehicular and pedestrian right of way. The signalized intersection also separates the conflicting movements into different phases and reduces the total number of crashes and crash severity. Often, the objective of making a safer intersection contradicts with the objective of mobility; however, an agency should not simply seek to improve mobility because productivity comes with improved safety. (FHWA, 2013)

In urban transportation, performance of signalized intersection requires significant attention because it represents the primary source of delay for urban roads. Saturation flow, lost time and the queue length represent the important parameters for the planning, design and control of a signalized intersection. The operating parameters, traffic condition, roadway parameters and environmental conditions may influence the operation and performance of a signalized intersection. (Hadiuzzaman et. al 2014 ). The HCM 2000, Australian based SIDRA software analysis package, the Canadian capacity guide and the Swedish capacity guide, all provide methods for estimating performance measures (Zhao et al and Teply et al). According to HCM (1985), capacity represents a planning level estimate that incorporates the effect of lost time and typical saturation flow rates. For the evaluation of intersection performance and determination of traffic signal timings, saturation flow remains as the basis. Factors that impact the saturation flow of a given lane or approach generally include the urban environment, local driver behavior, lane width, turning radius, gradient, pedestrian interference, parking or transit interference, interaction with priority, opposing or adjacent flows, and limited queuing or discharge space.( Tepley et al., 1991)After the initiation of the green phase, the first driver in the queue observes and react to signal change and accelerates through the intersection from a stand-still. This creates a relatively long first headway. This continues until a certain period when the start-up reaction and acceleration no longer have an effect on the headways. Hence, start-up lost time represents the additional time in seconds that the first few vehicles in a queue at a signalized intersection use beyond the saturation headway. The factors that affect the start-up lost time include vehicle type and road gradient, pedestrians in the intersection, perception-reaction time, which varies from driver to driver, and psychological factors. While, even at in ideal condition, due to physiological condition and other circumstances, start-up lost time varies; any sort of distraction may significantly impact his or her perception reaction and response time, which may influence both saturation flow and start up lost time.

Distracted driving has existed since the invention of the automobile. Billboards, people on the side of the road, fiddling with the air conditioning, tuning a radio, eating or parenting represent sources of both external and internal distractions. The emergence of the cell phone and especially, smart devices has created opportunities for users to be socially active while on the go. A cell phone distracts a driver visually, physically, cognitively and audibly (Rahman et. al. 2018). Studies also found that using a cell phone while driving appears riskier than any other distracted activities by drivers (Drews et. al. 2009). In 2013, the Centers for Disease Control and Prevention (CDC, 2013) reported that about 69% of the total drivers of the United States talk on their cell phone, 31% email or read and send text messages while driving. A 2014 report by the National Highway Traffic Safety Administration (NHTSA) focused on the behavioral factors that contributed to 32,999 highway fatalities and 3.9 million injuries in the US in 2014. A breakdown for the economic losses shows crashes involving distracted driving accounted for 17 percent ($46 Billion).

Researchers around the world have identified and estimated saturation flow variation due to lane type, peak hour, queue length, green time etc. (Abayneh., 2014, Bivina et. al. 2016., Li et. al 2003 and Shawky et al. 2013). Studies also identified the connection between startup lost time and saturation flow and delay variation due to vehicle type, perception reaction time. The cost of social and economic aspect of distracted driving is well established. Unfortunately, the connection between electronic device induced distracted driving, start-up lost time, saturation flow and their associated factors are still missing. The variation in different type of distracted driving (such as cell phone use, hands-free call vs hand-held call, texting, and emailing) and its correlation to startup lost time and saturation flow may give researchers valuable insight. This newly identified paradigm will help identify costs associated with mistimed signals and the operation inefficiencies that it introduces.



**Historical treatment of startup loss time and its role in traffic signal timing**

Saturation flow is a key input for optimal signal timing. A small variation in saturation flow values could affect changes in cycle length and thereby affect the efficiency and operation of an urban street system. A great deal of research on estimating saturation values has been done, taking into account prevailing conditions at signalized intersections. Various methods exist for determining saturation flow by observing queues of vehicles at an intersection and determining their respective headways, but little research has been carried out to evaluate the effect of longer green periods on saturation flow. (Khoshla et. al. 2019) The Highway Capacity Manual (TRB, 2000) prescribes an ideal saturation flow rate of one thousand nine hundred vehicles per hour per lane. An idealized view of saturation flow at a signalized junction is illustrated in Figure 2, the rectangular model of saturation flow rate (Turner and Harahap, 1993).

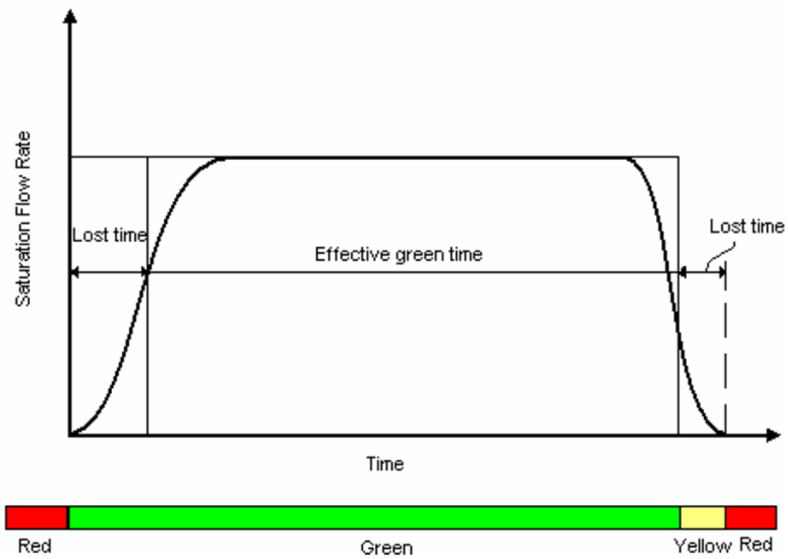


Figure 1:Typical Flow rate at a signalized intersection

Saturation flow is a macro performance measure of junction operation. It is an indication of the potential capacity of a junction when operating under ideal conditions. Ideal conditions (TRB, 2000) assume the following: 3,6 meter lane width; No heavy vehicles; Flat gradient; No parking or bus stops near the intersection; Uniform movement type, i.e only straight movement or only turning movement; and No pedestrians or cyclists.

Start-up lost time is another important parameter in performance of signalized intersections which may in turn depict the effect of behaviour of different drivers for different countries. Start-up lost time is defined as the additional time, in seconds, consumed by the first few vehicles in a queue at a signalized intersection above and beyond the saturation headway, because of the need to react to the initiation of the green phase and to accelerate (FHWA 2013). HCM (2010) indicates that start-up lost time is generally about 2.0 sec/phase. Factors affect start-up lost time are- Vehicle type and gradient; Pedestrians in the intersection; Perception/reaction time which varies from driver to driver, Psychological factors. Minh and Sano [3 defined that start-up lost time is the time lost due to driver reactions and vehicle acceleration.

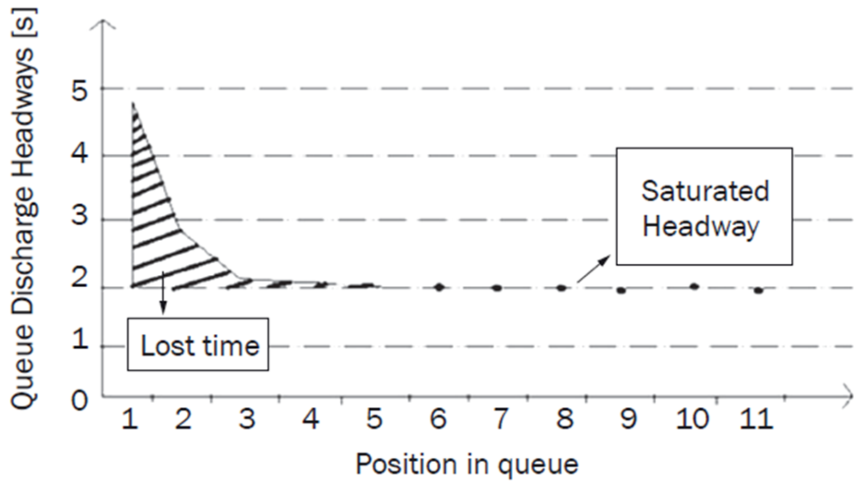


Figure 2 : Startup lost time at a signalized intersection

The study, "The Economic and Society Impact of Motor Vehicle Crashes, 2010," found that those crashes cost $277 billion in economic losses and $594 billion in societal harm, for a total of $871 billion that year. A breakdown of the figures for economic losses show crashes involving distracted driving accounted for 17 percent ($46 billion). Traffic signal management involves the planning, design, integration, maintenance, and proactive operation of a traffic signal system in order to achieve policy based objectives to improve the efficiency, safety and reliability of signalized intersection operations (Bilncoe et. al. 2015). Over the years, this area has received the most attention of the academic community. The theoretical work on which most of modern day signal timing is based is the research conducted in the United Kingdom in the late 1950s by Webster. The first formula for delay estimation that has been popular for delay estimation was first developed by Webster (1958). His equation is the following-

$$d = \frac{c(1-g/c)^2}{2[1-(g/c)x]} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{\frac{1}{3}} x^{2+5(g/c)}$$

Where the first term of the equation determines the delay when traffic flow is uniform and second term makes some allowance for the random nature of the arrivals, which is also named as random delay. Miller in 1963 developed another formula to calculate delay by estimating the average overflow queue. Most of the formulas developed for delay estimation later on were based on Webster model. Allsop (1972) and Hutchinson (1972) developed their formula based on the Webster formula, but Ohno developed his formula based on Millers approach.

This work was based on pre-timed control and has been incorporated into most traffic optimization and simulation models. The research was primarily focused on the investigation of delay at pre-timed intersections .Other researchers expanded this research to include the operation of actuated controllers. In 1969, Newell and Osuma showed the relationship between average delay and various controller settings at pre-timed and actuated intersections. They demonstrated that delay for an actuated signal was less than that for a pre-timed signal. This work was more of an investigation into intersection delay than signal timing. In 1976, Staunton summarized the work of various signal control researchers. This paper provided comparisons of delay produced by both pre-timed and actuated controllers under different demand conditions. Staunton demonstrated that full-actuated control with 2.5 second extensions would always provide better performance than pre-timed control.

These programs provided the foundation for the development of the signal timing optimization programs currently used in the Unites States. Much of the development work on Transyt-7F and Passer II was completed in the 1980's. While substantial improvements have occurred in recent years, the improvements have tended to be in the area of user interface improvements and migrating the programs from a mainframe computer environment to a desktop computer environment.

## Evolving Thoughts on startup lost time and saturation flow

Control, delay, queue length and cycle failure is some of the common measures to evaluate in the performance of intersections. (Zheng et al. 2013). Travel time is one of the largest categories of transport costs, and time savings are often claimed to be the greatest benefit of transport projects such as roadway and public transit improvements. Queue discharge patterns have been researched in the past, but only in recent times many studies are focusing on saturation flow and or start up loss time to evaluate the performance of an intersections. With increasing delays and congestion on our nation's streets and highways, finding effective ways to maintain acceptable levels of service is critical to satisfying users as well as protecting the environment. Varieties of road based transport modes catering to the transport demand ply in large numbers on the road system. As a result traffic and transportation problems are aggravating day by day. These problems are manifesting themselves in the form of increased traffic congestion, delays and subsequently causing wastage of fuels and creation of pollution and make it a hoard of residential, commercial and business activities. Lack of proper planning and designing of intersection signals, bus bays, parking areas etc are the main reasons for the cause of delays and congestions faced by road transportation.

Saturation flow is an important parameter that needs to be investigated in the performance analysis of signalization systems. When the previous studies were examined, it was determined that the method based on headway was widely used in literature. One of the oldest studies on the headway value at signalized intersections is the study conducted by Greenshields et al. In the study, the researchers examined the average headway depending on the queuing position and they found that the average headway value decreased from the first vehicle to the fifth vehicle in the queue and remained almost stable after the sixth vehicle until the last vehicle in the queue. However, several researchers have found that headway values decrease as the queue length increases.

Thus, Çalışkanelli has found that, if the vehicles waiting in the queue were considered based on their positions, no statistically significant difference could be determined in the headway averages of the vehicles waiting at the 2nd or higher queue positions. In other words, the vehicles in the queue at the signalized intersections under examination achieved the saturated headway state as the vehicles in the 2nd line. In this case, it might be stated that the headways obtained from the intersections did not display the generally observed clear tendency to decrease.

Khosla (2004), in a master's thesis at the University of Texas at Arlington, and Khosla and Williams (2006) studied the matter at four intersections in the Dallas–Fort Worth, Texas, metropolitan area. Khosla found that the flow increased with time into the green through about the first 20 s (the flows were reported in 10-s intervals) and then stabilized until the final one or two 10-s intervals, when it increased (presumably as an effect of rushing the clearance interval and considering that not all green periods were the same). Two causal mechanisms have been hypothesized to explain the effect of diminishing stopline flow from an emptying queue, assuming that it exists. One is that turning vehicles may be trapped in a long queue in the through lanes. They will depart the through lanes for the turning lanes during the green for the through vehicles, thus lessening the flow on the through lanes. A more severe cause of this effect is an approach that widens to additional through lanes as it approaches the intersection. As the departing queue works its way back to the narrower section, the stopline can only be fed by the cars stored in that narrower section, which would starve the capacity of the wider section at the stopline by some amount. The second hypothetical mechanism might be that drivers are no longer able to respond to the displayed green light because their position in the queue puts them too far away to see the signal. If the drivers cannot see the signal, their perception–reaction time may no longer overlap with that of drivers of vehicles in front of them as characterized originally by Greenshields. If they are reacting instead to the brake lights of the cars in front of them or to movement in an adjacent lane, some of the perception–reaction time might be added back into their initial headway. The common practice of increasing cycle length to increase capacity is based in part on the assumption that saturation flow remains constant once the initial lost time has been accommodated, and the effect of traffic departing from through lanes for turn lanes is ignored. In conclusion, the field data did not support the hypothesis that lost time builds back into the traffic stream as queues empty through very long greens. However, turning traffic leaves gaps in the through lanes, and the data at this site show that those gaps do result in a significant decrease in throughput. The less green time is used to serve a queue containing turning vehicles, the greater the maximum throughput in the through lanes. (Çalişkanelli , 2018 )

Driver start response time, which is an important indicator of driving characteristics, is another key parameter in the calculation of effective green time and determination of start-up lost time at signalized intersections. Institute of Transportation Engineers and Akçelik et al. both suggested 1.0 second for start response time. On the other hand, Bonneson suggested 1.22 seconds; Li & Prevedouros suggested 1.76 and 1.42 seconds for through and left turning vehicles, respectively. In AIMSUN simulation program, start response time for leading vehicles in a queue is recommended at 1.35 and Tong & Hung suggested 1.32 seconds for passenger cars and taxis. In AASHTO it is stated that this value may change between 1.0~2.5 seconds, considering different situations a driver may face. In Turkey, Çalışkanelli & Tanyel found the mean values for through and left and right turning vehicles as 1.48 s; 1.26 s and 1.39 s, respectively. They also suggested an empirical function for the prediction of start response time of drivers in the leading position of a queue at a signalized intersection:

$$tr = -0.149MNV - 0.136GN + 0.020CYL \quad (1)$$

where, *tr* is the start response time (seconds); MNV is the maneuver type (for through passing vehicles MNV=0, for right turning vehicles MNV=1 and for left turning vehicles MNV = 2), GN is the gender of the driver (1 for male and 0 for female drivers) and *CYL* is the cycle time (seconds).

Prior studies showed that several factors affect the startup response time as well as value and distribution of startup delay. These factors include- the turning movement (through, left and U-turn), queue length, intersection geometry and location, time of the day, weather condition, visibility of traffic light, phasing timing and sequence etc. (Shawky et. al and Bonneson investigated that larger left turn radius resulted lower headways. It also showed that queue length and lane volume has negative impact on headway of the first few vehicles. A study in Turkey identify startup loss time increases with increases in cycle time and lower startup loss time on left or right turning lanes. Study also finds out Startup loss time decreases when lane width increases and startup loss time increases when bus percentages becomes more than 20-25% (Çalişkanelli , 2013). Lower acceleration capability of heavy vehicles compared to passenger cars results higher headway and higher startup loss time at an intersection (Ramsey et. al.).Weather condition i.e. raining also impacts startup loss time. An investigation by Sun et. el says that saturation flow decreases by 3-7 percent due to rainy weather and startup loss time rises by 21-31 percent in each lane. (Sun et. al).

Many studies in startup loss time used different techniques to calculate the saturation headway and startup loss time. Jin et al. investigated that departure headway in a queue follow a log normal distribution. Li on the other hand used Bayesian analysis to calculate the headways based on loop detector data . A study in Ireland by Gunay (2012)automatic plate recognition technology to investigate the headways among the drivers . Tan et al. analyzed the relationship between startup loss time and departure headway and proposed distribution model to start up loss time estimation. Tang et. al. 2019 suggests a new method based on time space diagram and shock wave theory to estimate lost time at right turns ( comparable to left turns in the United States). Proposed method calculates more accurate loss time in terms of waiting area and bring short cycle lengths when demand ratio is between 0.65 and 0.80. (Tang et. al. 2019). Li et al. (2015) aims at comparing drivers startup loss time of the first two vehicles at signalized intersection based on data collected through a videography technique and used Pearson's correlation to determine the correlation between first two vehicles.

There are many headway distribution model has been used by researchers using empirical traffic data. In general these models has been categorized as single statistical distribution models and mixed models. Single statistical distribution model includes- Weibull distribution (2005), the Erlang distribution, Cowan's M3 and M4 distribution (Dong et. al. 2014). Sun and Benekoal (2005) used Weibull distribution model in work zone traffic. Al-Gahmdi (2001) proposed four headway distribution models- negative exponential distribution for the flow rate, shifted exponential and gamma distribution for the middle flow rate and Erland distribution for the high flow rate. Riccardo et al (2014) suggested Weibull distribution is more accurate one for rural roadways. When it comes to mixed distribution model the popular model that has been used by researchers are- double displaced negative exponential distribution (DDNED), combination of normal distribution and shifted negative distribution, a combination of negative exponential distribution and shifted negative exponential distribution model, generalized queuing model etc.(Dong et. al.2014). Zhang (1999) et al. investigated that DDNED model and log normal distribution model best fits for high occupancy vehicle lane (HOV) and regular lanes. Researchers in recent times is considering the impact of vehicle types on the headways. Weng et al (2013) found that headways are strongly dependent on the type of leading and following vehicles. So they investigated and suggested that lognormal distribution is best suited to car-car headway type as well as car-truck headway and inverse Gaussian distribution is best fit for both truck-car and truck headway.

**Treatment for signal operational condition improvements.**

The 2012 National Traffic Signal Report Card score is a 69, equivalent to a D+ letter grade. The 2012 score is a modest four-point improvement over the 2007 result of a D letter grade (NTSRC-2012). Delays experienced in highway travel have been steadily increasing during the past 20 years. Delays at traffic signals contribute an estimated 5 to 10 percent of all traffic delay or 295 million vehicle-hours of delay on major roadways alone. Further, the 2011 Urban Mobility Report notes that in its reporting areas, 61 percent of the street miles in the cities had some level of traffic signal coordination that reduced delay by 21.7 million person hours (Schneider, 2019).
The following are some specific examples of signal timing optimization and signal system improvement benefits experienced in various communities nationwide, as documented in the United States Department

of Transportation’s Intelligent Transportation Systems for Traffic Signal Control, Deployment Benefits and Lessons Learned (FHWA, 2019):

- The Traffic Light Synchronization program in Texas demonstrated a benefit-cost ratio of 62:1, with reductions of 24.6 percent in delay, 9.1 percent in fuel consumption, and 14.2 percent in stops.
- The Fuel Efficient Traffic Signal Management program in California demonstrated a benefit-cost ratio of 17:1, with reductions of 14 percent in delay, 8 percent in fuel consumption, 13 percent in stops, and 8 percent in travel time.
- Improvements to an eleven-intersection arterial in Saint Augustine, Florida, showed reductions of 36 percent in arterial delay, 49 percent in arterial stops, and 10 percent in travel time, resulting in an annual fuel savings of 26,000 gallons and a cost savings of $1.1 million.
- A project in Syracuse, New York, that connected intersections to a communications network produced reductions in travel time of up to 34 percent. Coordinated signal systems improve operational efficiency and can simplify the signal timing process.
- In areas of rapidly changing or unpredictable traffic volumes, adaptive signal timing control may improve system performance by 5 to 30 percent, but should be applied with caution to intersections or corridors.
- Spending less than one percent of the total expenditure on highway transportation would lead to a level of excellence in traffic signal operations. It would be an investment with a 40:1 benefit-cost ratio and would result in benefits of as much as $45 billion per year. This corresponds to a price of less than $3 per U.S. household resulting in savings of $100 per household per year. (2, 16)

**Evolution and Intensification of Distracted Driving Due to Electronic Devices**

According to National Highway Traffic Safety Administration (NHTSA, 2019), 3,166 people died due to distracted driving and main reason of those distraction was using cell phones. A cellular phone, once used only for call receiving or call dialing, has now become an essential device for each person to maintain his or her everyday life. With the improvement of modern technology, cell phone usage is not just limited to dialing and receiving calls by a handheld (HH), a headset (HS), or a hands-free (HF) device; rather, smart phones have created opportunities for users to be socially active while on the go. NHSTA also indicates that in 2017, around 5.3 percent of drivers use cell phones either handheld or hands free at a typical daylight driving time. (NHTSA, 2019). A cell phone distracts a driver by visually, physically, cognitively, and audibly impairing them. Drivers become visually impaired when they look away from the roadway to see who is calling, physically impaired when they dial a cell phone number using a handheld device, and cognitively and audibly burdened when they engage in a conversation. Thus, call receiving, call dialing, texting, chatting, or even a simple conversation can increase the chances of decision impairment (Consiglio et. al., 2003; Hosking, Young, & Regan, 2006; Mazzae, Lissy et al, 2000; Patten, Kircher, Östlund, & Nilsson, 2004; Schreiner, Blanco, & Hankey, 2004; Tornros & Bolling, 2005).

Several studies have specifically focused on the decrease of driver performance, which increases the probability of crashes. Drivers tend to interact with their cell phones when any opportunity arises especially during the waiting time at the traffic signals (Huth et al. (2015). Sanchez et al. (2014) statistically confirmed that most of the visual-manual interactions started at the red traffic light although as per their observations, half of the drivers were already using the phone before arriving at the signal. They also found that most of the drivers stopped their visual-manual interactions but continued with their calls beyond the red light. Caird et. al., (2004) showed in their research that drivers using a cell phone respond to a sudden event almost one fourth of a second later than undistracted drivers. Their research also shows that if the time to take emergency action goes beyond one and half seconds, the fatality risk increases from 6.6 to 100%. Recent research (Mazzae et al., 2004; Schreiner, Blanco & Hankey, 2004; Törnros & Bolling, 2006) also confirms that dialing either an HF or HH cell phone can have serious consequences on driving performance. Schreiner, Blanco and Hankey (2004) reveal that reaction times to visual events increase when using a HH device. Strayer & Johnston (2001) also find that cell phone users react slower, have longer following distance, and take longer to recover to following speed. A comparative study between drunk drivers and cell phone using drivers was carried out by Strayer et al. (2006). They found that drivers using the cell phone had slower reaction time, longer recovering time for the lost speed due to braking and were involved in more accidents (tableX)

Table 1: Means and Standard Errors (in Parentheses) for the Alcohol, Baseline, and Cell Phone Conditions (Strayer et. al 2006)

| | Alchohol | Baseline | Cell Phone |
|---|---|---|---|
| Total Accidents | 0 | 0 | 3 |
| Brake Reaction Time (ms) | 779 (33) | 777 (33) | 849 (36) |
| Maximum braking force | 69.8 (3.7) | 56.7 (2.6) | 55.5 (3.0) |
| Speed (mph) | 52.8 (2.0) | 55.5 (0.7) | 53.8 (1.3) |
| Mean following distance (m) | 26.0 (1.7) | 27.4 (1.3) | 28.4 (1.7) |
| SD following distance (m) | 10.3 (0.6) | 9.5 (0.5) | 11.8 (0.8) |
| Time to collision | 8.0 (0.4) | 8.5 (0.3) | 8.1 (0.4) |
| Time to collision <4s | 3.0 (0.7) | 1.5 (0.3) | 1.9 (0.5) |
| Half recovery time (s) | 5.4 (0.3) | 5.3 (0.3) | 6.3 (0.4) |

Strayer et al. (2004) came up with inattention-blindness hypothesis in which drivers are incapable of actually "seeing" the environment around when they are involved in cell phone because the content of the conversation draws their attention away. Drews et al. (2010) concluded that using cell phone while driving is riskier than any other distracted activities by drivers. Beede et al. (2005) analyzed the impact of phone use (hands free) and lack of attention to the signal detection. Their study found that even though the research involved hand free devices, lack of situational awareness and traffic violations were still persistent. They witnessed significant delays during change of light from red to green for the drivers involved in cell phone conversations and the drivers took one-third longer time when resuming speed from stop signs while they were involving in cell phones than during normal condition.

Table 2: Means and standard deviations for response time data (Beede et al. 2005)

| | | **without phone** | **with phone** | **total** |
|---|---|---|---|---|
| **Stop sign delay (s)** | | | | |
| | *Without signal task* | | | |
| | Mean | 6.83 | 7.41 | 7.12 |
| | Std Dev | 1.72 | 1.72 | 1.72 |
| | *With signal Task* | | | |
| | Mean | 6.98 | 7.07 | 7.03 |
| | Std Dev | 1.17 | 1.73 | 1.45 |
| **Traffic light delay** | | | | |

| | | | |
|---|---|---|---|
| *Without signal task* | | | |
| Mean | 1.37 | 1.79 | 1.58 |
| Std Dev | 0.41 | 0.43 | 0.42 |
| *With signal Task* | | | |
| Mean | 1.41 | 1.46 | 1.44 |
| Std Dev | 0.33 | 0.45 | 0.39 |
| **Reaction time event** | | | |
| *Without signal task* | | | |
| Mean | 0.83 | 0.84 | 0.84 |
| Std Dev | 0.11 | 0.15 | 0.13 |
| *With signal Task* | | | |
| *Mean* | 0.88 | 0.81 | 0.85 |
| Std Dev | 0.1 | 0.07 | 0.09 |

While researchers focus on the proximity of cell phone usage location, various other researchers considered frequency and type of usage. A research by Bernstein & Bernstein (2015) compared the frequency of cell phone use while stopping at intersections and at motion which showed, about 14.5 % of drivers text while stopping at red traffic light which is almost five times when drivers are in motion. In contradiction to this, Naturalistic Driving Studies by Xiong et al. (2015) revealed that drivers using cell phones were often found driving in lower speed at intersections. Higher speed drop was shown by drivers involved in Visual and Manual tasks. These trends show that drivers try to compensate for their distraction by reducing speed. A study in Australia discussed the type and frequency of mobile phone use while driving. (White et al. (2010). They found only few drivers were using the hands-free kit while many were using hand-held mobile devices and equal risks were found to be associated in both the cases. Patten et al. (2004) found that the content of conversation the driver is involved influences more for the distraction than the type of devices he is using. Harbluck et al. (2007) experimented with hands- free voice-based devices while driving and found drivers only looked ahead and often skipped the peripheral glance and mirrors. The drivers paid less attention to traffic signal and the environment around the intersections. White et al. (2010) also reported that drivers involving in in phone calls were in higher percentages in case of hands-free kit than hand-held devices. However, texting and reading messages while driving did not depend on the type of devices used.

When drivers are involved in cell phones in presence of complex traffic situation, Alm & Nilsson (1995) found an increase in reaction time to 0.560 seconds for young drivers and 1.460 seconds for elder drivers. Involvement of a driver in such activities increased their workload and stress levels leading to reduced situational awareness. Caird et al. (2008) found a mean increase in reaction time by 0.25 seconds due to cell phone tasks. A study in India revealed that involving in complex texting while driving increases the reaction time to 204 % considering pedestrian crossing the road as one of the roadside events (Choudhary & Velaga, (2017).

Different experimental studies also have been conducted to estimate the reaction time while using a cell phone. Haque and Washington (2014) designed a simulated event when a pedestrian enters a zebra crossing and the result showed that reaction time increases by 40% when a driver is using a cell phone. Leaung et al (2012) designed a similar kind of simulated event by creating a hazardous event of sudden appearance of a heavy truck. Result showed a significant increase in reaction time. Consiglio et al. (2003) investigated reaction time at critical traffic signals. Evaluation showed 72 millisecond increment of reaction time for drivers using a cell phone. Patten et al (2004) assigned Peripheral Detection Task (PDT) to drivers while driving. They detected 72 millisecond and 261 millisecond of increased reaction time for drivers involved in a simple and complex conversation on cell phone respectively.

**Research Needs and Future Research**

The saturation flow, headway and lost time are derived from historical data. This may have been collected during various combination of circumstances such as electronic distractions at intersections. With new technology such as smart phones and in-vehicle entertainment systems, signal timing now requires to consider driver distraction and consequent start-up delay at intersections.

The research team conducted an initial study to understand the factors contributing to start-up delay, focusing on driver's distracted behaviors such as using a cell phone, eating, talking to other passengers, grooming, or being distracted by outside objects. The research team conducted data collection at one of the busiest intersection- Matlock Rd at Arbrook Blvd in the City of Arlington, Texas. The intersection is located near different business centers and is close to the interstate highway that connects Dallas to Arlington. The intersection has three NB and SB through lanes and two left turn lanes. Both the EB and WB direction has two through lanes and two left turn lanes. In addition to that, EB has a dedicated right turn lanes. Three trained surveyor observed vehicles while they stopped at the intersection during red indication, and manually recorded any distraction behaviors identified earlier. The surveyors also logged if the distracted behaviors persisted after the signal changed to green indication. The study collected 296 distracted behaviors in the span of 3.5 hours on through lanes, which accounts for 17 percent of total traffic at the intersection. Figure X illustrates the different types of distracted behaviors for different lanes and shows that at least 55% of the distracted drivers were using cell phones or other electronic devices in each lanes. Eating and talking to other passengers are the second and third most common behaviors.

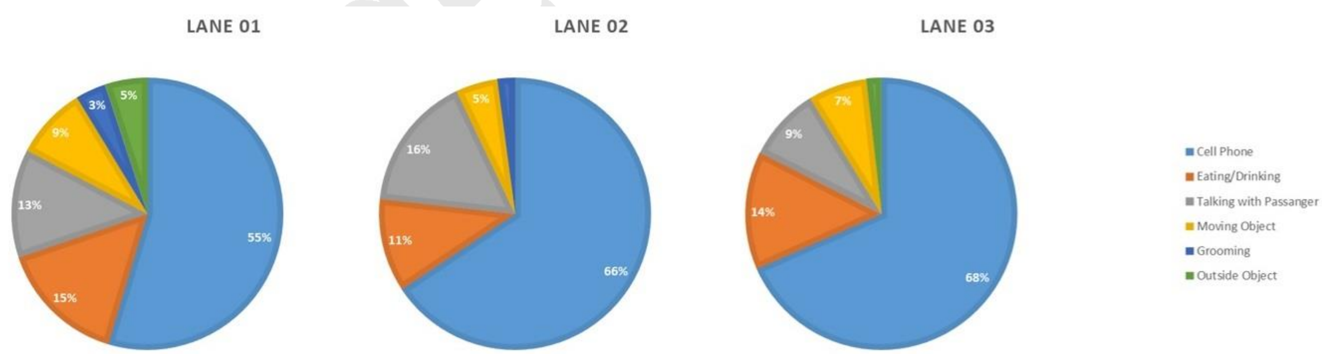


Figure 3: Distraction Percentage of different lanes.

Similarly, type of cell phone usage such as call receiving, call dialing, texting, chatting and emailing are various means of distraction created by electronic devices. The role of each of this distraction on the driver will help evaluate startup lost time for better operational performance of signalized intersection and will thus reduce delay. On the other hand, policy makers may get insightful information about the type of distraction that creates more congestion and take necessary policy steps.

Roadside survey or video-based data can be used to identify the type of distraction and time frame during the on-set of green signals. Roadside survey can be used to identify specific situation at the on-set of green which is otherwise unavailable due to poor visibility. Based on the two sets of data, total delay and associated temporal and environmental variables can be identified. Video based data collected can be used to develop various parameter change such as lost time and saturation flow rate. The driver output model can be built connecting various elements of Saturation flow rate along with start-up lost time, demographics of driver and driver distraction while driving. Once the total simulation model is developed, the model needs to be validated with another set of data to calculate saturation flow and startup delay due to distraction.

**Conclusions**

The use of electronic device by drivers poses a significant safety risk; however, distractions appear likely to impact operations as well as safety. The purpose of this synthesis study was to focuse on the saturation flow, startup lost time and driver distraction due to electronic devices and any state-of-the-art method for signalized intersection performance evaluation. Distracted driving may cause a vehicle to travel at a lower than expected speed or fail to move when receiving the right-of-way. Failure to response immediately when the signal turns green may have an impact on start-up lost time. At the on-set of green, the perception-reaction time varies from time to time and place to place due to- distracted drivers, psychological factors and other circumstances.

Distracted driving has existed since the invention of the automobile. Driver start response time, which is an important indicator of driving characteristics, is another key parameter in the calculation of effective green time and determination of start-up lost time at signalized intersections. The emergence of the cell phone and especially, smart devices has created opportunities for users to be socially active while on the go. A cell phone distracts a driver visually, physically, cognitively and audibly.

The preliminary study showed that at least 55% of the distracted drivers were using cell phones or other electronic devices in each lanes. Eating and talking to other passengers are the second and third most common behaviors. This study is currently looking into the connection between various types of cell phone usage and startup lost time.

Most of the vehicle delay estimation are based on through field measurement and real time experiments. But these methods are time consuming and expensive in nature. This models need accurate calibration and lots of constraints. Another challenging issue for real time delay calculation is the delay experienced by vehicles decelerating towards a queue or red light, delays experienced by vehicles stopped at the intersection or in a queue and delays experienced by departing vehicles. So the future of delay estimation should be focusing more on automated simulation methods and artificial process. A simulation platform representing the actual field environment and fully calibrated replication of individual behavior will provide simplified mathematical solutions. Also, simulation models are comparatively less expensive and very less time consuming.

Electronic device distraction requires careful exploration to quantify any costs associated with the operational inefficiencies that it introduces. Unfortunately, very few studies have been done to understand the connection. This synthesis study focuses on the aforementioned factors and any state-of-the-art method for signalized intersection performance evaluation. The key directions for future research include investigating the factors that contribute to distractions at signalized intersections, the frequency of occurrence and the magnitude of impact.

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