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Original Research Paper

Opportunities and challenges of smart mobile applications in transportation

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ARTICLE INFO

Article history:
Available online 9 November 2016

Keywords:
Smart mobile applications
Distracted driving
Distracted walking
Transportation safety
Travel information

ABSTRACT

Smart mobile applications are software applications that are designed to run on smart phones, tablets, and other mobile electronic devices. In this era of rapid technological advances, these applications have become one of the primary tools we use daily both in our personal and professional lives. The applications play key roles in facilitating many applications that are pivotal in our today's society including communication, education, business, entertainment, medical, finance, travel, utilities, social, and transportation.

This paper reviewed the opportunities and challenges of the applications related to transportation. The opportunities revealed include route planning, ridesharing/carpooling, traffic safety, parking information, transportation data collection, fuel emissions and consumption, and travel information. The potential users of these applications in the field of transportation include (1) transportation agencies for travel data collection, travel information, ridesharing/carpooling, and traffic safety, (2) engineering students for field data collection such as travel speed, travel time, and vehicle count, and (3) general traveling public for route planning, ridesharing/carpooling, parking, traffic safety, and travel information.

Significant usage of smart mobile applications can be potentially very beneficial, particularly in automobile travel mode to reduce travel time, cost, and vehicle emissions. In the end this would make travel safer and living environments greener and healthier. However, road users' interactions with these applications could manually, visually, and cognitively divert their attention from the primary task of driving or walking. Distracted road users expose themselves and others to unsafe behavior than undistracted. Road safety education and awareness programs are vital to discourage the use of applications that stimulate unsafe driving/walking behaviors. Educating the traveling public about the dangers of unsafe driving/walking behavior could have significant safety benefits to all road users. Future research needs to compare accuracies of the applications and provide guidelines for selecting them for certain transportation related applications.

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2016.11.001

1. Introduction

Smart mobile applications are software applications that are designed to run on smart phones, tablets, and other mobile devices. The applications are commonly known as "mobile apps" or simply "apps". In this era of rapid technological advances, mobile applications have become one of the primary tools we use daily both in our personal and professional lives. The applications are downloadable from mobile application distribution platforms for free or purchase. These applications play key roles in facilitating many applications that are pivotal in our today's society including communication, education, business, entertainment, medical, finance, travel, utilities, and social.

The history of the mobile app began with the first development of the mobile device and the first mobile phones whose microchips required the most basic of software to send and receive voice calls in 1973 (Bates, 2014; Rajput, 2015). Typically, the early applications were small arcade games, ring tone editors, calculators, calendars, and so forth. The rapid market and technology evolution of mobile contents and applications started in the beginning of the new millennium. Unlike the conventional programming environment of standard cell phones, operating systems for smart phones (Windows mobile, Symbian, RIM, Android, Mac iOS) opened development of third-party software. During this era, mobile companies tried to make mobile products that are more attractive for customers by introducing more and more applications. These rapid technological advances were partly motivated by the need for companies to increase revenues and making mobile devices that are easy to use and intuitive. Every company started and tried to facilitate the process of development so that users are able to customize their devices (Future Market Insight, 2016).

In July 2008, Apple opened its iOS App Store which was the first application distribution service (Apple, 2008). This set the standard for applications distribution services for other mobile companies. This led to consumers using their mobile devices as a way of connecting to the web. Consequently, mobile phones started to be known as smartphone due to their numerous capabilities. Mobile and software developers realized that they could take mobile website capabilities up with new applications named mobile applications. The applications would have the same functions and capabilities as websites designed for a desktop or laptop. The websites were scaled down so that they would fit mobile devices. This led to a plethora of mobile applications being developed and implemented. In 2010, the word "app" was listed as the "word of the year" by the American Dialect Society (2011). Early applications for mobile apps were for email, calendars, contacts, stock market, and weather information. High demand from users led to mobile applications being used in mobile games, factory automation, banking, order-tracking, and ticket purchases (Future Market Insight, 2016).

The mobile industry has continued to grow rapidly, with a total of 3.6 billion unique mobile subscribers at the end of 2014 and an addition of 1 billion subscribers predicted by 2020 globally (GSMA intelligence, 2015). This global penetration rate is approximately 60% of the current users. Key trends in the U.S. smartphone industry for July 2015 indicates 198.5 million people in the U.S. owned smart phones (79.1% mobile market penetration) during the three months ending in July (ComScore, 2016).

In transportation sector, the early use of mobile applications was mainly for navigation and location-based services. As of 2016, the mobile applications are used for many transportation related applications including engineering education, traffic data collection, travel information, route planning, and ridesharing. On the contrary, some applications create challenges especially in areas of enforcement and traffic safety. For example, some of the applications can detect speed camera or radar gun and alert the user to slow down a certain distance before crossing the location. These applications work similar to radar detectors that are widely available commercially but they are free or cost much less. Studies showed that radar detector users have more speed convictions compared to the general driver population (Cooper et al., 1992). Thus, increased availability of such applications may encourage some drivers to exceed highway posted speed limits, which could endanger safety of the traveling public (Cornelissen and Rudin-Brown, 2010).

In literature, there are numerous applications available purposely for traffic safety, transportation emission quantification, transportation data collection, and navigation (Dutzik et al., 2013). Realizing the potential of the applications in transportation area, several states' departments of transportation (DOT) agencies have already implemented mobile applications that showed real time travel information to the traveling public. Similarly, the National Highway Traffic Safety Administration (NHTSA, 2013) has created a mobile application named "safercar". This application is aimed to make it easier for consumers to access and submit information about important vehicle safety concerns. The Tennessee Department of Transportation (TDOT) developed its mobile application "TDOT SmartWay mobile app" for monitoring traffic operating speeds and incident notification (TDOT, 2014). With respect to traffic congestion, some states have implemented parking applications to help alleviate traffic congestion. According to USA TODAY (2013), "In Washington, the nation's most congested city, half a million users have registered for "ParkMobile". These are some evidences that there is great potential for mobile applications in transportation discipline. Despite of this only few efforts exist that quantifies or describes the vitality of mobile applications to transportation agencies and the traveling public. With increase in more sophisticated applications, most of the problems that are evident in transportation can be made simpler and more cost-effective to address than before.

Although there are many mobile applications that offer prevalent transportation related applications, no study was found that have documented their benefits and dis-benefits. For this current knowledge limitation, this study aims to review mobile applications with potential applications in transportation and identify their potential benefits and dis-benefits. The study reviews applications listed on the mobile applications distribution platforms for Apple App Store, Google Android Market, Blackberry World, Samsung App Store, Ovi Store, and Windows Store. Specifically, the objectives of this paper are listed below.

- To identify and summarize key features of available mobile applications with potential applications to the transportation industry;
- To document current usage of mobile applications by transportation agencies and public;
- To summarize opportunities and challenges of mobile applications in the transportation industry;
- To recommend directions for future research directions.

It is worthwhile mentioning at this point that there are many applications in the market, hence, the applications presented throughout this paper are representative samples and do not capture all the existing and/or future applications. The paper focuses on the features common to the majority of the existing applications. In the end of the review, overall summary of the potential benefits and dis-benefits of the applications in transportation area are summarized.

2. Smart mobile applications in transportation sector

Smart mobile applications have the potential benefits to improve traffic operations and safety. As stated earlier in this paper, we searched the mobile applications distribution platforms and categorized the applications into different areas of applications in transportation industry. The review results were further categorized into potential opportunities and challenges. The opportunities are categorized according to the possible utilization in the transportation industry especially in areas of transportation data collection, route planning, ride-sharing, travel survey, traffic safety, parking, travel/traffic information, energy consumption, and emissions. The challenges were grouped into enforcement of traffic laws and safety. The following sections present the details of these opportunities and challenges for some applications found in the literature.

2.1. *Route planning*

Table 1 summarizes some of the smart mobile applications for route planning. The table provides its acronym used and a key feature of each application. In general, route planning applications are intended to assist the traveling public to navigate cities easily, quickly, and to determine an efficient route from a point of origin to the point of destination (Borole et al., 2013). Most navigation applications use maps from other providers like Google maps, GPS manufacturer maps like TomTom, Navi and those provided by transportation agencies. The applications range from simple to complex design and usage. Simple applications simply provide directions from starting location to one destination for one travel mode. On the other hand, complex applications allow the user to enter multi-destinations, perform route optimization, and cover multiple modes of transportation available in that particular area.

Most of these applications allow the user to choose the best route depending on several factors including route length, grade, and speed. The applications for bicyclists and walkers for route planning provide road users with an option of selecting the shortest or quietest bike or walk routes. Most of these applications provide route grade information and therefore help non-motorists choose routes based on their ability to handle grades. With respect to applications covering

Table 1 – Route planning applications.

Acronym used	Key features
Easy Route Finder	Find a distance and time to drive/walk to reach a destination from a given start point.
Runtastic Road Bike Tracker	Search bike routes and tracks bike rides via GPS: distance, duration, speed, elevation gain, pace, calories burned, etc.
Voyager: Route Planner	Find an optimal (fastest) route to travel to multiple locations.
Journey Pro	Provide the best route using various combinations of available modes and real time journey planning around some major cities in UK.
GPS Route Finder	Find the easiest and fastest driving/walking route from a starting to a destination point.
Driving Route Finder	Find the driving routes between any start and end locations.
ROUTE 66 Navigate	Provide lane guidance and speed limits for optimal guidance for car driving navigation.
MySmartRoute	Optimize routes for multiple locations from a start point.
Smart Ride	Find the best travel connection based on multimodal travel information service in Austria.
BestRoute	Provide an optimal multi-destination route planning.
Route Planner	Find the easiest and fastest travel route to a destination from a start point.
Road Tripper	Provide trip planning, easily find places, save places, and send them to your favorite navigation app.
ESPO Free–Route Planner	Optimize many destinations by car or on foot.
Route4Me	Gives the most optimal multi-destination routes making trips quick and easy.
RouteOptimizer	Optimize the route from a start to a destination.
Bike Route Planner (& Tracker)	Assist route planning and navigation to cycling and walking.
Bike Hub Cycle Journey Planner	Find the quickest or quietest cycling routes.
Trip Planner	Help a traveler to organize everything needed for a trip.

transit modes, mostly provide basic information like schedule and station locations. Advanced applications provide commuters with real time arrival times, stop locations, and real time vehicle delays for major transit agencies and station facility information (e.g. parking fare, lift, wheel chair access, toilets, etc.). These applications utilize the mobile device built-in GPS to provide riders with their current location and then suggests the nearest station and the time that the next couple of trains will be leaving the station. Further, the applications provide platform information allowing the user to know in advance the leaving and arriving platform for their selected train.

2.2. *Ridesharing/carpooling/vanpooling*

Table 2 presents some of the smart mobile applications that are designated for ridesharing/carpooling/vanpooling needs in real time. Traditional carpooling is not a new idea even in developed countries. About 10% of U.S. commuters share a ride everyday either in a formal carpool or as "casual carpoolers" (ACS, 2011). Ridesharing contributes towards reducing emissions by reducing the number of vehicles on roadways, increases travel options, reduces parking demand, and, more importantly, reduces transportation costs to participants (Dutzik et al., 2013). Real time ridesharing has the potential to make a difference by offering a new mode of transportation that dynamically matches drivers and riders, and automatically distributes the cost reduction of the commute between them while reducing security and safety concerns. In essence, smart mobile applications for ridesharing match drivers and passengers with common origin and/or destination. Some applications allow real time ridesharing and therefore drivers may pick-up riders on the way to their destination. The applications require users to register to support matching, payment, and, for some, a backgrounds check. Further, some applications in addition to route matching, the applications use other factors like gender, non-smokers, social network, and user ratings. The rating features are then used to determine whether the rider and driver should be matched in the future or not.

2.3. *Traffic safety*

Table 3 shows some of the smart mobile applications that are designed to improve traffic safety. In general, applications in this category serve as a vehicle black box, voice-to-text, managing teenagers/inexperienced drivers, and reporting vehicle accidents. The applications that serve as a vehicle's black box mostly save vehicle data such as speed, date, time, and location. In addition to this, the applications continuously video record driving and save the information. These applications use collision sensors to register incidents whenever there is abrupt deceleration. In such events these applications automatically display emergency contacts saved by the user like family, police, and insurance agents. In line with the black box applications, accident-reporting applications make it easier for the user to contact emergency personnel, document accident details, file a real time insurance claim, and obtain legal advice from a qualified attorney in the user's area. Furthermore, some of the applications are designed to provide distraction-free driving. They integrate mobile-built in GPS and sensors to detect motion and disable cell phone and smartphone features such as talk, text, email, and surf the web while driving to stop distracted driving. On the other hand, some applications would shift manual forms of distracted driving such as holding a phone on your hand to auditory forms of distracted driving. Importantly, there are applications that are designed to limit younger and teenager driving behavior and distracted driving. These applications keep teen drivers distraction-free and make them focus on the road, prevent texting and phone calls while driving, and keep a log of any communication and send report to the parent.

NHTSA (2013) developed an application known as "SaferCar" to provide important information and functions that can help users to make informed safety decisions involving their vehicle. The application allows the user to

Table 2 – Ridesharing/carpooling/vanpooling applications.

Acronym used	Key features
Uber	Allow a traveler to request a ride from a private driver and get picked up within minutes in more than 50 countries.
Avego	Determine future matching between the rider and the driver.
SideCar	Let a traveler choose a car, driver, price and ETA, so you always get the ride you want.
Car2go	Allow a one-way car sharing service, allowing members to pick up a vehicle at one location in the city and drop off at their destination.
Podorozhniki Smart Ridesharing	Connects drivers and passengers moving same way.
RideShare4Less	Allow drivers and passengers find each other in real time to ride together.
Tifandi-Share Your Taxi Ride	Designed to allow travelers to share taxi rides in the entire world.
Zebigo	A program that Seattle's King County organizes for vanpools.
Share-E-Ride	Allow people in India to carpooling together from point to destination that they mutually decide.
Southwest Carpool V2	Allow a traveler to find others to share travel with to work and study in the southwest.
Adelaide Carpool	The South Australian carpool that match a traveler with other people traveling in the same direction.
Carma Carpooling	Match a traveler with nearby people who want to share trips.

Table 3 – Traffic safety applications.

Acronym used	Key features
ZoomSafer	Automatically detect driving and provides reminders to use your device safely while driving to reduce distractions.
Text'nDrive	Read your emails and let you reply to them all using voice.
IGuardianTeen	Keep teen drivers distraction-free and focus on the road to prevent texting and phone calls while driving, keeping a log of any communication and send report to the parent.
TextArrest	Limit distracted driving by prevents the temptation of teen drivers to use their cell phones while driving.
Drivesafe.ly Pro	Feature a one tap operation and auto-on functionality that allow a user to seamlessly interact with a phone without texting or emailing while driving.
Steer Clear Mobile	Help young drivers to reinforce positive driving behavior and stay aware of hazards on the road by giving them tips on how to drive and what to look out for in a variety of weather conditions.
SafeCell 360	Provide parents with oversight on the use of their driver's access to smart device while driving.
Cellcontrol	Determine when you are driving and eliminate the temptation of a driver to talk, text, email and surf the web while driving to stop distracted driving.
tXtBlocker	Disable cell phone and smartphone features when a younger driver is driving.
SaferCar	Provide important information and functions that will help the user to make informed safety decisions involving their vehicle.
Speed Watcher Free	Provide an analog speedometer and odometer that gives audible and visible warning/alert when a set speed limit is exceeded.
AT&T DriveMode	Silence incoming text message alerts, and helps avoid distractions allowing a driver to stay focused while driving.
No Texting While Driving App	Block all incoming calls and puts an auto-reply to all texts coming in.

record vehicle information so that they can be notified by NHTSA if a safety issue becomes known. This also makes simple to submit complaints to the NHTSA when the user believes there is a possible safety problem with the vehicle. The "help installing child seats" application ensures that passengers ride safe. It provides assistances with driving directions to where one can get assistance on making sure child seats are properly installed, no matter where a person may be. The "safety headlines and alerts" application receives important news and information from the NHTSA, as well as recalls notices on your list of vehicles.

2.4. *Parking information*

Table 4 shows a list of smart mobile applications that are available to provide parking information. They make parking easier for people or agencies as they travel through a city or area. Statistics show that across the UK, it takes an average of 6 min and 45 s to find a suitable parking space (The Telegraph, 2013). In Los Angeles, 28% of its drivers spend 11–20 min circling for a parking space (USA TODAY, 2013b). This translated to more than 950,000 miles in search of a parking spot, producing roughly 730 tons of carbon dioxide emissions and consuming 47,000 gallons of gas.

Real time parking availability is not a new concept. However, smart mobile applications revolutionized technology by making parking information accessible via mobile rather than computer or laptop websites or upon arrival at the parking garage. The average communication time between the parking sensor server and the mobile application is 30–45 s (USA TODAY, 2013). Most parking applications provide users with information like real time data on parking availability, pay-by-phone options, and alerts the user on remaining meter times (Smart Parking, 2016; Parking Network, 2016; Plasma, 2016). Using mobile device built-in GPS, other parking applications allow users to tag where they parked their vehicle and therefore save user's time in case they forget where they parked a vehicle. According to USA TODAY (2013), in Washington, the nation's most congested city, half a million users registered for "ParkMobile". In California, the Los Angeles "express park" uses mobile applications to track downtown parking availability of 6000 metered spots and 7500 city-owned spaces. In Indiana, the Indianapolis "ParkIndy" program uses smart mobile application to track availability of spaces among 3600 metered spots. In addition to saving user's time, the service helps parking managers judge when and how often parking spaces are turned over, therefore allowing for more efficient parking management.

2.5. *Transportation data collection*

Table 5 presents a list of smart mobile applications for transportation data collection. The applications can be used for counting road traffic, passengers in vehicles, and pedestrians (Abeygunawardana, 2010; Deutsch et al., 2012; Vlassenroot et al., 2015). These types of applications use a built-in GPS to show current location, maximum and average speeds. Some applications use the built-in mobile device camera to detect and analyze motion and record object speed by holding up the mobile device towards the moving object. After data collection, some applications allow the user to email the data file in text/csv format. The data file contains date, speed and unit, time, preset distance

Table 4 – Parking information applications.

Acronym used	Key features
Find my Car	Help to locate where you parked your car.
Pocket Parking Meter	Combine a parking meter, a car-finder and a notebook.
Nice City Pass	Gather information on the various modes of transportation-pedestrian, bicycle, car, and public transport to help travelers organize their trips.
FSU Tranz	Find out whether the parking garages at Florida State University are too full to go to or just right.
Heathrow Airport Flight Tracker	Provide live flight tracking, notifications of flight status updates, interactive terminal maps, travel planning tools, security guide, shop and restaurant listings and more through Heathrow Airport.
Best Parking-Find Parking	Steer drivers toward the cheapest and most convenient parking garages and lots in 105 cities and 115 airports throughout North America.
Parkopedia Parking	Provide map and list every parking space in the world.
Central Parking	Find nearby parking locations in NYC, Boston, Philadelphia, Washington DC and over 40 other cities in the US.
Park Me Right: Car Locator	Remember where you parked your car.
Parkmobile	Provide a way to pay for parking using your cell phone.
SpotHero-Find Parking	Find parking, compare prices and reserve a spot for up to 50% off the drive-up rate.
MyCar Locator Free	Easily locate and guide the user back to the car.
Parkdroid	Save the parked car location and help to find it.
Parknav-Best Street Parking	Provide an optimized turn-by-turn navigation route to find open free, metered or zoned/permit parking in the US and Germany.

between mobile device and detected object, and direction of travel. Time stamps enable easy synchronization with other point-based speed data collection including loop detectors for comparisons of their accuracy. The direction of travel enables data collection for opposing traffic movements which is particularly relevant for two-lane highways. In addition to speed, these applications have timer that records each movement that passes through the camera, therefore enabling collection of traffic count data. Likewise, traffic count file includes date, time, and direction. These types of applications provide easy and cost effective ways to collect traffic operation data. So far, no study has evaluated their accuracy in data collection or compared the data collected with the ground truth such as loop detectors.

Apart from collecting speed and vehicle counts, other applications collect traffic turning movement counts including cars, pedestrians, bicycles and trucks. The data output can be downloaded in different file formats for further analysis. The output files can also include peak hour summary, peak hour factors, intersection geometry, and intersection GPS coordinates. The main concern with these applications would be that observers are likely to spend more time looking at the

Table 5 – Transportation data collection applications.

Acronym used	Key features
TurnCount	Count vehicles and pedestrians entering an intersection.
R&S Counts	Allow counting cars for a company, receiving count information, and submitting traffic count electronically when you are done.
SpeedClock	Use the camera to detect and analyze motion and a reference distance to calculate the speed of an object.
Speed Tracker Free	Help to gather all the necessary trip statistics: speed, time, distance, heading, elevation, etc.
DigiHUD Speedometer	Show useful speed and distance information for your journey.
Car Dashboard Pro	Replaces speedometer and a car home dock.
SpeedView: GPS Speedometer	Show your current, maximum and average speed, direction, total distance, and time traveled.
Speedometer Free Speed Box	Track your speed and distance.
Vehicle Speed Logger	Track, monitor, and keep a minute-by-minute log of speed, date, time and location.
Speed Gun	Measure the speed of a moving object.
Speed Limiter	Give the user five different speeds to choose and give an alert if you outside your current active speed limit range.
Speed limit	Check vehicle speed and warn if you drive faster than the speed limit to avoid speed tickets.
Trip logger	Detect device movement and automatically track mileage.
Mileage Log+	Track and log vehicle mileage for tax deduction or reimbursement.
Saga Traffic; Trip Tracker and Travel Surveys	Collect location data about the user's movement and travel.
Traffic Survey	Manual traffic volume count at a road intersection.

screen to ensure they tap at the right place which could be difficult especially at busy intersections.

In areas of travel survey data, several applications can be used to collect travel and location data using mobile device built-in location sensing capabilities such as GPS. They allow the user to track a vehicle or multiple vehicles locations, store frequent trips made, calculate vehicle fuel economy, mark important locations such as tollbooth, and track vehicle mileage. Such data collected are useful to transportation planners for travel demand modeling and forecasting purposes. Also, these data can assist to improve the accuracy of information that transportation agencies collect when conducting regular travel surveys for improving transportation operations and services. The application of this nature if utilized by transportation agencies, have the potential to reduce costs associated with travel data collection and data collection efforts. With respect to travel time data, reviewed applications were found to provide such data to drivers, therefore this data may be difficult for transportation agencies to obtain except during surveys where travelers may be able to provide more accurate travel time data.

2.6. *Vehicle fuel consumptions and emissions*

Table 6 displays a list of some smart mobile applications related to fuel consumptions and emissions produced due to combustion of different types of fossil fuels. They allow the user to create a detailed calculation of the amount of vehicle fuel consumptions, gas expenses, and miles traveled. The applications also help the user to calculate carbon emissions produced by different types of vehicles per trip traveled. Theoretically, these applications promote awareness to the users on how much emissions their vehicles are releasing into the environment per trip and miles traveled. This information could change travel behaviors for some travelers especially those who are environmentally sensitive to choose modes of transport that produce less emissions into the environment such as walking for short trips, public transportation, carpooling, and so forth. The results of such travel behavioral changes could contribute to a significant reduction in emissions, hence, improved air quality.

This category of applications use the mobile device's built-in accelerometer to measure vehicle performance metrics such as vehicle's 0–60 acceleration, quarter mile elapsed time, horsepower, lateral G's, etc. Simulation-based emissions models like MEET and COPERT typically use such performance measures to estimate emissions (Demir, 2012). Therefore, these applications have the potential for use as portable emissions measurement systems (PEMS) at a comparatively lower cost than commercially available PEMS.

2.7. *Travel information*

Table 7 presents a list of smart mobile applications for travel information. Most of these applications show real time traffic information so that the traveling public can be aware of highway or public transit status. Most applications provide key traffic information including live updates on accidents as soon as they appear across the road network, ongoing and planned roadwork listed by road, region, and county, and real time average travel speed and travel time between major junctions. Moreover, some applications use built-in GPS to locate users, therefore providing targeted traffic information in real time. Some applications provide more detailed information about lane level updates such as which lane is blocked by an accident or construction activities. This real time travel information enables road users to make an early lane change to unblocked lanes or change a route. This information also allows motorists to choose travel routes based on current real time traffic information. Such real time traffic and roadway information are crucial for improving traffic operations. In the end this has the potential to overall reduce travel time, reduce traffic congestion, and reduce vehicle emissions.

2.8. *Transportation related challenges*

Table 8 displays various smart mobile applications that pose challenges in transportation industry. As stated earlier in this study, there are some smart mobile applications currently available that provide certain opportunities to the users but that could pose significant challenges to transportation and enforcement agencies. The major

Table 6 – Fuel consumption and emission applications.

Acronym used	Key features
AccuFuel™	Track and monitor vehicle fuel efficiency.
Gas Manager	Create a detailed dashboard with your fuel consumption, your gas expenses and the miles you have traveled.
Fuel Economy Calculator	Monitor vehicles fuel economy and track how much you spend on fuel.
Dynolicious	Generate accurate vehicle fuel performance test results.
Greenfuel	Help to locate alternative fuel stations currently in the United States.
FuelConsumption	Calculate amount of fuel, distance traveled, and fuel consumption.
iLogFuel Lite	Give a detailed analysis of miles per gallon on urban, combined and extra urban cycles.
myFuelLog	Keep track of your fill-ups and car expenses and track time and location.
Fuel Fare	Calculate fare per person of your last trip and cost per mile.
Refueling Database	Keep records of refueling for all your vehicles.
Real-time Fuel Costs	Help to find the cheapest gas prices.
Carbon Emissions Calculator	Allow passengers to estimate the emissions attributed to their air travel based on origin-destination and travel mode.

Table 7 – Travel information applications.

Acronym used	Key features
Beat the Traffic Plus	Provide real time traffic specific to your route.
Sigalert.com	Feature real time updates on traffic and road speeds in the U.S.
ATC Delays	Allow the user to view airport ground stops and delays, arrival and departure delays, and airport closures.
Georgia 511	The official traffic app of the Georgia DOT, provides real time access to traffic and travel information.
VDOT 511	The official traffic information from the Virginia DOT, provides access to current and future traffic and roadway information.
NMRoads	Provide New Mexico and interstate motorists with mobile access to up-to-date travel and traffic information.
UK Bus Checker	Show when buses arrival and destination for 300,000 bus stops in the mainland UK.
CDOT Mobile	The official app from the Colorado DOT, provides real time travel data on its highways.
MoDOT Traveler Information	Show current work zones, incidents, and weather-related road conditions on state-maintained routes in Missouri.
Traffic Cameras + Toll and Travel Information	Allow to monitor traffic cameras around the world (including Australia, New Zealand, England, USA and Europe) and the user can also monitor toll and travel cards.
TDOT Smartway	Provide up-to-the-minute traffic information in Memphis, Nashville, Chattanooga, and Knoxville in Tennessee.

challenges found in this review are essentially related to traffic law enforcement and unsafe driving behavior. In particular, the challenges are on speed enforcement and traffic light changers. For speeding, some applications can detect and alert a driver about the presence of speeding cameras or radar guns within a certain range from highway patrol. The majority report live police, mobile speed cameras, red light cameras, fixed speed cameras, known enforcement, and combo cameras. On the contrary, these applications can pose challenges to highway patrols in enforcing traffic laws. On the positive side, some applications also report information such as accident, construction zones, road hazards, traffic jams, children at play, bush fire, dangerous intersections, dangerous curves, flooded roads, etc., which can help to improve traffic safety and operational efficiency of highways. These type of speed detector applications would be of benefit to temporarily and locally reduce excessive speeding drivers but unlikely to result in overall benefits to traffic safety (Cornelissen and Rudin-Brown, 2010).

Other smart mobile applications are designed to change traffic signals equipped with a pre-emptive sensor from red to green. These applications work similar to the mobile infrared transmitter (MIRT), a device used by buses and emergency vehicles to control traffic lights. The homemade transmitters have led certain cities to use specially encoded MIRTs. The unsuccessful Safe Intersection Act of 2005 had proposed a federal offense for an unauthorized person to use any traffic pre-emption devices. Subject to testing, however, if these applications are to work, then they pose a major challenge

Table 8 – Smart mobile applications challenges.

Acronym used	Key features
Trapster	Help drivers by reporting traps and hazards such as accidents, construction zones, traffic jams, live police, when spotted.
Cobra iRadar	Allow users to access live radar/laser detection and allow users to share and receive alerts in real time to avoid traffic enforcement such as speeding and red light cameras.
AES Malaysia	Automated enforcement system avoidance app in Malaysia.
PhantomAlert	Give audible and visual alerts while driving on the surrounding such as speed traps, red light cameras, speed cameras, and DUI check points.
Glob	Warn while driving close to speed cameras, speed traps, accidents or road works.
Police Radar	Show police traps, police radar, speed cams, speed traps, parking attendants, speed cameras, accidents and other traffic disturbances in your area added by application users.
Waze	Give road alerts along your route and find the cheapest fuel prices around you shared by the community.
Traffic Light Changer	Trigger a preemptive sensor on a traffic light that causes it to change from red to green.
CamSam	Give alerts in real time and warns against all fixed speed cameras worldwide.

both to transportation professionals and enforcement agencies.

2.9. *Summary of potential benefits and dis-benefits of smart mobile applications*

Based on this review, the most important benefits that smart mobile applications offer related to transportation purposes are mainly on improving transportation efficiency and safety while dis-benefit is mainly on road users' distractions. Subsections that follow discuss the potential benefits and dis-benefits in detail.

2.9.1. *Improving transportation efficiency*

Significant utilizations of smart mobile applications can be potentially very beneficial, particularly in automobile travel mode to reduce travel time, cost, and vehicle emissions (Lissy et al., 2000; Whipple et al., 2009). This is due to the fact that automobile travel is the dominant mode of transportation in most urban cities around the world. Although significant efforts have been made since the mid-1990s to promote ride-sharing, carpooling/van pooling, and public transportation, as of 2016, automobile is still the dominant mode of travel. As a result of this dominance, vehicle tailpipe carbon dioxide emissions contribute about 95% of total carbon dioxide emissions produced in transportation sector-related sources (USDOT, 2010). Any significant shift in automobile occupancy and travelers decisions to use efficient transportation network system based on real time information can substantially increase transportation system capacity and reduce vehicle emissions. In the end this can minimize the impacts of greenhouse gases on climate change, global warming, and air quality standards. Promoting awareness programs that focus on individual travelers' decisions and cities to make smart travel choices can improve transportation efficiency, hence, rebuild human habitat and make living environments greener and healthier.

2.9.2. *Improving transportation safety*

The most important benefit of these smart mobile applications is that they can make roads safer by preventing road users' from mobile distractions. These distractions take the form of manual, visual, and cognitive. Any application that tends to limit road users to divert their attention from the primary task such as driving, biking, or walking has the potential to improve safety. Preventing the temptation of road users to use their smart phones could significantly reduce incidences of distracted driving, distracted biking, and distracted walking. In turn this could save lives, injuries, and property damages. According to distracted driving statistics, auditory distraction is less dangerous compared to the manual distraction (Strayer et al., 2013). This study found that talking to another passenger in the car or using a cell phone, whether using a hands-free device or holding the phone in your hand, all had comparable levels of distraction for the driver.

2.9.3. *Dis-benefits of smart mobile applications*

Road users' interactions with applications manually, visually, and cognitively could divert their attention from the primary task of driving, biking, or walking. Any action or situation that tends to divert traveler's attention from the primary task of either driving, biking or walking is termed as distraction. Distractions can be categorized into three forms of distractions, visual, manual, and cognitive. Safe travel especially on roads require maximum attention from all road users. Distracted road users such as drivers expose themselves and others to unsafe behavior than undistracted. As the use of mobile smart devices among non-motorists and motorists continue to rapidly proliferates, the incidences of distraction-related crashes are expected to escalate. In literature, the effects of distracted driving cited include reduced awareness of driver's surroundings, increased reaction and braking times, increased incidences of collision, reduced vehicle speed, greater following variability, greater lateral variability, and reduced response time to the lead vehicle (Caird et al., 2008; Fitch et al., 2013). Distracted drivers generally expose pedestrians to high risk of harm than themselves. Similar effects of distractions are also expected to bikers and pedestrian. Road safety education and awareness programs are vital for discouraging the use of applications that stimulate unsafe driving/walking behaviors. Educating the traveling public about the dangers of unsafe driving/walking behavior could have significant safety benefits to all road users.

3. Conclusions

In conclusion, on overall, most applications could provide important benefits individually or collectively especially in reducing travel time and cost, reducing traffic congestion and vehicle emissions. The potential users of these mobile applications are.

1) Transportation agencies. Agencies can take advantage of applications, particularly those related to travel data collection, travel information, ridesharing/carpooling, and traffic safety. For example, for travel information, the Departments of Transportation in Georgia, Virginia, and Colorado have mobile applications that show important travel information to the traveling public. Another option is collaboration between the transportation agencies and applications developers. For instance, the High-ways Agency in UK reached an agreement to feed up-to-date traffic information from England's motorways and major roads into the “hands free traffic talker england” application for smart-phones. The application provides traffic information covering unplanned incidents such as accidents and congestion, including lane closures and other restrictions due to improve-ment works. In addition, public transportation organizations such as the UK bus checker also have mobile applications that provide real time bus arrival and departure information for over 300,000 bus stops in mainland UK.
2) Engineering education. Students in the engineering discipline can use the applications to conduct field travel data collection practices such as speed, vehicle count, and traffic turning movements at signalized intersections. As

the technology advances, most of the college students are likely to own smart mobile devices because they are economical and handy tools.

3) General traveling public. The general traveling public can benefit from those applications especially those related to route planning, ridesharing/carpooling, parking, traffic safety, and travel information. Significant usage of these applications can assist motorists to reduce travel time and costs related to vehicle fuel consumptions.

There are many possibilities for some transportation agencies to use smart mobile applications in transportation sector. Based on the findings of this review, the following is a list of recommendations for future research directions.

1) Most of the existing smart mobile applications have not been fully evaluated for their accuracy in travel data collection. Further research could explore how accurate the smart mobile applications are for travel data collection. For instance, comparison of speed data collected using different mobile applications with trusted ground truth such as loop detectors would be useful. Such comparison will assist the developers of the applications to fine-tune their algorithms.
2) Several transportation agencies have already developed and implemented smart mobile applications. In such locations, there is a need to conduct a before and after analysis of the effect of smart mobile applications particularly in improving traffic safety and operational efficiency of highways. If the results show positive outcomes, then other transportation agencies might be more inspired to implement similar applications in their jurisdictions.
3) Different smart mobiles are known to have different operating systems and/or versions. Such differences could result in different accuracies for the same application. Research should compare the accuracies of different smart mobiles and provide guidelines for selecting smart mobiles for a certain transportation related application.
4) Road safety education and awareness programs are vital for discouraging the use of those mobile applications that stimulate unsafe driving behaviors. Educating the public about the dangers of unsafe driving behavior such as excessive speeding could have significant safety benefits to all road users. In this context, the traveling public should be made aware that although they may run from law enforcement personnel, still excessive speeding is dangerous and kills.

In summary, these research opportunities identified above in this area are of paramount importance and timely since many road users are being distracted especially by electronic devices these days. The research opportunities highlighted are also interesting given the rapid development of communication technologies and the increasing coverage of smart phones, which has the potential to increase traffic crashes. This review can assist policy makers to prioritize different interventions for crash reduction by setting out policies and strategies that will directly affect the most critical category of distracted road users who are subjected to smart mobile distractions. In addition, the review can assist travelers to make personal decisions regarding their travel choices to reduce travel time and cost while minimizing vehicle emission pollution.

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