Speech-To-Text (STT) based mobile apps can aid Citizen Reporting Program (CRP) to reduce reckless driving in resource-constrained situations

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Abstract

Most of the data gathering devices used for monitoring driver's behaviour require large storage, strong cellular signals, and unlimited internet. Touching mobile devices, during driving, is prohibited by many law enforcement agencies. There are situations, where people get stuck on roads with a low battery, low device-memory, and no mobile network. The drivers in such situations are not able to use 'Citizen Reporting Program' (CRP) effectively in reporting against reckless drivers. This paper presents a framework of the CRP aided with Speech-To-Text (STT) based mobile app to reduce reckless driving in such 'Resource-Constrained Situations' (RCS). An STT-based mobile app was designed, developed, and tested as a tool for this purpose. It could convert speech to text without a cellular network, capture the geolocation, and send data to a server on the network or internet availability. We tested its reliability for converting speech to text and got a 'Word Error Rate' (WER) of less than 5%. We tested its functional usability and got a score of more than 71% on the 'System Usability Scale' (SUS). The survey showed a favourable response of over 70 % in reducing reckless driving via CRP in RCS if aided with such STT-based mobile apps.

1. Introduction

The World Health Organization (WHO), 2018, reports road accidents to be the cause of a global annual death toll of 1.35 million people and financial loss equaling about 3% of GDP (gross domestic product) of many countries [1]. More than 80% of road accidents are very closely related to a driver's behavior. Many young drivers correlate aggressive driving with power. Therefore, getting profiled as risky drivers by 'In-Vehicle Monitoring Systems' (IVMS) may not deter them from aggressive driving, especially if they can afford to pay a high insurance premium. But the moment they see a police car, they start driving carefully to avoid penalty points. As per data reported by the National Highway Traffic Safety Administration (NHTSA), people who receive citations for driving violations are less likely to commit the same offense again, at least for some time [2]. Since touching mobile devices, during driving, is prohibited by law at many places some unaccompanied drivers may think of using other forms of 'Human-Computer Interaction' (HCI) such as mini mobile Electrooculogram (EOG), whereby they can blink their eyes to type texts. However, the performance of EOG that uses video cameras may fluctuate depending on the cellular connectivity, the jerks during driving, sunshade, or sunlight or may not at in certain resource-constrained situations (RCS) [3].

To reduce road accidents, almost every district of every state of every country has one or the other form of driver's initial training programs for new drivers to get a driving license. Also, there are penalty system cum corrective training programs for road traffic rules violators. Still, we hear of thousands of road accident-related deaths every year caused by 'Reckless Driving' (RD) even though drivers are aware of their driving styles, behavior patterns, and related road crashes. Not because there is a shortage of technological tools available to monitor the driver's behavior but because of the thought that '*It will not happen to me*' or '*I will not be caught.*' The fear of getting caught or reported and the thinking that '*this can happen to me*' has a substantial effect on the driver's behavior. Because of this reason, many law enforcement agencies keep cars with flashing lights at many junctions or medians and keep the overhead cameras installed even if they are non-functional.

Law enforcement agencies have been encouraging more people to participate in CRP where people can call to report traffic violations, because the number of deployed 'Police Per Thousand Residents' (PPTR) has been declining, as per data shown in the '*Bureau of Justice Statistics*,' even though the US population is growing at a reasonably good rate [4]. As per the '*population division 2019 graph*' of the United Nations Department of Economic and Social Affairs, the world's population of drivers in the age group of 15-64 is also rising at a steady rate [5]. Therefore, any tool that helps CRP can generate support for law enforcement efforts and increase the perception in the driver's community that reckless drivers will be caught [6]. These CRPs seem to be resulting in more electronic tools being used by people to capture images, videos of reckless drivers, accident-related incidents, and accidents for insurance claims as well as personal or public safety. This trend is justified by the rising size of the global dashboard camera market, as shown in the graph of 'the global dashboard camera market 2012-2020 projection' [7].

When RD is reported to law enforcement agencies under CRP, it goes through a process wherein the offending driver may get determined by the local police either as a case for a 'warning letter' or civil infraction or misdemeanor charge depending on the driver's reported driving history or evidence. Many a time, risky drivers are given a letter to go through a '*Defensive Driving Course*' which helps them in getting refreshed with driving rules associated with driving risks of their violations and also getting rid of penalty points. '*Defensive Driving Course*' has been observed to reduce the number of accidents, at least until its effect wanes out [8].

Whether traffic tickets and CRPs aided with STT-based apps, would be more effective or In-Vehicle Monitoring Systems (IVMS) in reducing reckless driving, in RCS, can also depend on the economy and culture of the country or place. A study was conducted in Qatar regarding the effect of various strategies in correcting unsafe drivers in which delayed rewarding of the safe drivers was rated number one, followed by automated enforcement methods, followed by traffic tickets [9-10]. Traffic tickets may be rated 3rd for its effectiveness in Qatar, which is one of the richest countries in the world [11-12] with a high GDP of \$124,930 per capita in 2019, and custom prohibits women from performing community service for traffic tickets. But at places where the cost of living is high as compared to average income, drivers try to avoid hefty traffic penalty points first [13]. It implies that in places with poor infrastructure, especially in developing countries, if a large percentage of the population starts reporting against RD, via CRP, it might create a kind of domino effect and psychologically encourage more people to be more alert and start reporting against RD. If current CRPs are aided with additional tools, it could be even more effective in reducing RD, especially in RCS.

The remaining of this article is organized as follows: Section 2 presents the related work, highlighting the gaps in the literature that the paper addresses. Section 3 describes the technology/ methods. Section 4 presents the experiments. Section 5 presents a video-based survey and responses after the experiments. Section 6 presents the experimental results and analysis. Section 7 has a discussion on implementation challenges and opportunities. The last section, 8, concludes the paper with some future perspectives.

2. Related Works

This section describes the relevant In-Vehicle Monitoring Systems (IVMS), the CRPs, and their reviews, in the context of resource-constrained situations (RCS), *in the subsections 2.1 to 2.4*. In subsection 2.5 we present a brief background of the solution to fulfil the requirement gaps.

There are many devices and mobile apps deployed by companies like Waze, Metropia, Mapquest, and Mercer, to name a few, that can help gather a considerable amount of driver data on their driving patterns and provide analytics to its fleet owning customers [14]. Drivers' behaviour is monitored via IVMS devices installed in their vehicles, to reduce risky driving. The insurance premium is decided based on driver's pattern of driving, a concept encouraged by many insurance companies referred to as 'Usage-Based Insurance' (UBI) [15], [16]. Thanks to falling cost and easy availability of 'Information Communication Technology' (ICTs), large transportation, and fleet management companies, have started using telemetry devices, Global System for Mobile Communications, Global Positioning System (GPS), Onboard Diagnostic (OBD), GPS trackers, on-board-cameras, telematics, and dash-cams to collect travel data cost-effectively. These devices are installed in vehicles with software that sends data to cloud-sourced servers for monitoring and analytic reporting on the device logs [17].

Many companies have started tracking, benchmarking, and training their drivers to create more economical and environmentally efficient fleets. Insurance companies have started using this information to monitor driver behavior to reduce their costs on insurance settlements and to offer their customers more flexible coverage terms. Thus, ICT devices and IVMS, have started helping several companies to improve commercial driver's risky driving behavior. Still, these devices and resources are not always cost-effective for families, private and independent drivers. A study by Deloitte reported that a large % of young drivers in the UK show an unwillingness to use telematics boxes when offered by insurance companies - 58% for cost-effectiveness and 92% for intrusiveness reasons [18]. Many of these devices may not even work very well in resource constrained situations 'RCS' of poor or intermittent network.

In the US market, the number of small OBD devices with mobile apps, such as Bluedriver Professional OBD2 [19], Verizon HUM [20], and Autobrain [21], are being promoted for small businesses and families and are gaining popularity. Android and iOS-based mobile applications such as Aviva RateMyDrive [22], StateFarm DriverFeedback [23], and AXA Drive (in Belgium) [24] and Greenroad [25] are popular in Europe. Smartphone-app based telematics systems are slowly gaining momentum amongst young drivers and families because of increasing sensing capacities, cost-effectiveness, and better user-control over their smartphone devices. In developing countries, these IVMS are at a very nascent stage because of cost, required infrastructure, and procedures. Therefore, CRPs aided with STT-based mobile apps seem more feasible option, in resource-constrained situations.

Based on the data gathered from law enforcement agencies and their partners who have been working on designing and implementing various preventive and corrective programs for risky drivers, CRPs and other such campaigns have resulted in many levels of success. For example, NHTSA's high-visibility enforcement program could reduce '*driving while talking on a hand-held cell phone or texting.*' Observed hand-held driver cell phone usage dropped from 6.6% to 2.9% in Hartford (Connecticut), and from 3.7% to 2.5% in Syracuse (New York State) [26]. Since reporting against risky drivers results in a positive effect; therefore, it is better to report all forms of risky driving and traffic violations, if possible, at least to build the history of unsafe drivers for their correction in the long term. The following are some of the significant ways to report against RD under CRPs, in RCS.

- Dial-in regular or emergency local police phone numbers e.g. 911, 100, 101,102, 112, etc.
- Websites/ Portal to report against RD. These portals could be run by Federal/ Central or state government or private organizations.
- Dash-cams with Apps or connectable to smartphones e.g. Vava Dash-cam, Nexar, Garmin + Amazon Alexa, etc.
- Device Independent Apps, i.e., RecklessRadar.com

2.1. Review of the Dial-in Regular or Emergency Local Police Phone Numbers to Report against Reckless Driving (RD), in RCS

Each country and state have their own designated emergency phone numbers to report against reckless and dangerous drivers. Some examples are given in *Appendix A1*.

2.1.1. After calling these emergency police numbers, one needs to fulfil legal formalities of providing many personal details before a complaint is lodged. This is further followed upon by law informant agencies, which is a very time-consuming process, and many times, one has to wait for a long time. Anonymous reporting is not allowed.

2.1.2. Sometimes people may misperceive the risk of a careless driving as reckless driving. People may not have network or intermittent network in RCS, and they may need to keep trying calling these numbers. This may clog all lines. Therefore, it is not a good idea to always call emergency police numbers. Police emergency numbers must be used for reporting severe emergency such as very dangerous driving or an accident. Calling local police or emergency numbers has a different purpose. Ideally, people should be calling emergency numbers as a last resort, for reporting against RD.

2.2. Review of Websites/ Portal to Report against RD, in Resource-Constrained Situations

Law enforcement agencies of each country and state have their own designated web portals to report against reckless and dangerous drivers. In addition to that, there are private agencies which support state law enforcement agencies, in gathering and analysis of information via their websites, portals and mobile apps, some examples of which are given in *Appendix A2*.

2.2.1. Central, federal, and state government websites are excellent tools to report against RD from the comfort of home/office. They are free, and personal data is not likely to be used

for advertising or commercial purpose, but they collect a lot of personal information, and it takes a long time to gather and provide all information at a time. Usually, these websites are many times very confusing and have no option for anonymous reporting.

- 2.2.2. Privately owned websites are more structured; therefore, easy to use with minimum data to fill and maximum data to select from a drop-down list. They allow anonymous reporting against RD as guest users without asking for too many personal details. Their essential reporting services against RD are free to use, and they also offer other services and useful analytics reporting to their premium members on a monthly subscription. They have often had affiliations to attorneys, insurance companies, and law enforcement agencies. These are slowly getting the attention of and subscription from younger people. They are competing for memberships and offer many incentives but still are not very favoured option because of the fear of misuse of personal data for advertising or commercial purposes. However, the websites/ portals mentioned in subsections 2.2.1 and 2.2.2 can be primarily used from home or office where internet connection is very good, so logically, these are not very suitable options for resource constrained situations (RCS).

2.3. Review of In-Vehicle Monitoring Systems (IVMS), Devices and Apps, in RCS

- 2.3.1. These IVMS devices and apps such as Bluedriver Professional OBD2, Verizon HUM, AXA Drive, provide a large amount of near-crash database for data mining and analytics reporting. But the data provided may not reflect actual risky behaviours of the driver if drivers get conscious of the presence of the device and start behaving in a different or alert manner [27]. There is also a privacy issue of providing too much personal information to service providers and insurance companies.

- 2.3.2. These devices and apps require constant satellite networks and or internet connectivity. The driver or owner of the vehicle needs to pay monthly/yearly rental/subscription charges for using these devices and related services. Therefore, a significant majority of families do not find it cost-effective. For the above reasons, the IVMS devices and apps do not seem to be a very suitable options, in RCS, in collecting information against reckless driving.

2.4. Review of the Dash-cams, Mobile Devices, and Related Apps, in RCS

There are many dash-cams, mobile devices, and related apps, such as mentioned in *Appendix A3*, that are very popular and useful for recording risky drivers' behaviour. These videos can be uploaded to many websites anonymously to report against reckless drivers as guest users without asking for too many personal details. They provide a large amount of data for evidence and analytics. However, most of these dash-cams consume a large amount of battery, require large memory for effective functioning when connected to smartphones or internet devices. For sound quality video recording with relevant information, a co-passenger is required because many of the dash-cams can be difficult and stressful to operate primarily for people who struggle with technology. Some Dash-cams like voice-activated Garmin with Alexa can be very handy, but it requires high-speed internet connectivity to work correctly.

RecklessRadar.com's mobile app, as well as the website, are primarily based on the Google map. If one has registered one's mobile number, it will track the registered mobile's location and display the location of another mobile owner nearby if any risky behaviour is

reported against the owner of the vehicle of that mobile. It requires a strong cellular network and or internet connection to display the location of the car on the map. Also, it can sometimes be very distracting when cars are moving through busy roads/freeways. Thus, these apps and dash-cams do not entirely fulfil the requirement of the above RCS but seem pretty close to fulfilling the conditions of the niche area.

A quick high-level review of subsections 2.1 to 2.4 of section 2 reveals that CRP options listed above seem to be better suited in RCS than IVMS options. On closer level review, one would realize that one would need to pull over to call the police and wait for a long time for their response. Alternatively, one would need assistance from a co-passenger or strong mobile network signal or internet connection to report against a reckless driver. However, not many people have the required resources available at critical moments such as these, especially in developing countries. This situation arises many times when unaccompanied persons are driving on a crowded street or freeway around reckless drivers, where they do not have a co-passenger to assist them and cannot touch an electronic device as per the local law. Another such situation is where a smartphone or dash-cam memory is almost full, or battery is running low, and remaining is required to be saved for emergency purposes. Another such situation is when a person cannot pull over to call the police or wait for a long time to get a response and then more time to provide the required details to fulfil legal formalities.

Further review of relevant information mentioned above related to IVMS, CRPs, web searches, reveals that the above information is not enough, and some more tools are required to address the issue of the above situations to report properly against RD. External feedback data and triggers received from people would help to investigate the already available data to start taking more targeted corrective actions, such as issuing tickets, training, incentives/disincentives, suspension of driving license, etc. [28].

2.5 A Brief Background of The Solution to Fulfil the Requirement Gaps.

To cover these requirement gaps we will describe an STT-based mobile app framework 'Talk-To-Ticket' (T2T), in the next technology section, that tries to aid the CRP, in resource constrained situations (RCS). However, before that we would present the rationale behind the development of the T2T app, to give a brief contextual perspective. There were many reasons to develop the T2T app, some of them are mentioned below:

- The more number of times the information is edited and time-lapses, the chance of error becomes higher, and authenticity becomes lower.
- It is more convenient to store all the relevant information in a folder and send it to a service provider with the tap of a button. Rather than to text the information to another person, update that later, find a service provider and then send the updated information to the service provider.
- In many countries, road and traffic safety agencies and law enforcement agencies are managed by different organizations, and service providers can play the role of coordinating agencies. For example, in India, Motor Vehicles Department works under the Ministry of Road Transport and Safety while crime and law enforcement fall under the police department, and they need a good amount of coordination to correct the situation of RD.

- We could not find a feasible, usable STT-based mobile app that could work well for our experiments, in the resource constrained situations to aid CRP.

3. Technology and Methods of the STT-based App that could Aid CRPs in the Resource Constrained Situations (RCS)

Based on the review above, the closest device or app we could use to meet all the resource constraints mentioned this research was 'Garmin plus with voice supported Alexa.' However, Garmin with Alexa uses too much battery in RCS. We also found issues with the quality of recorded data with Garmin with Alexa, because of frequent disconnections, in RCS. So, we designed, developed, and tested an STT-based app 'Talk-To-Ticket' (T2T).

The key fundamentals behind this new T2T app was to utilize some of the existing functionalities of the android and use them in novel form with the additional program codes, to fulfill the requirement gaps of the RCS. To the best of our knowledge, this app framework is unique and innovative. *The key components of the 'T2T' app framework work as follows:*

- Android, Windows, and iOS devices have transcribe or voice to text conversion options *even without an internet connection* [29], [30]. APIs are available for simple tasks to record short text like license plate numbers [31], [32]. The T2T app developed for this purpose, used the standard Speech-To-Text (STT) conversion API available in Android phones with OS Version 2.3 and above.
- Most of the Android devices have Bluetooth microphone port, voice recording port, screen to display, and folders for storing the usage of these data.
- High-speed internet connection is required by Google Voice, and Cortana to find an answer to complex queries or searches, but the simple task of converting STT and storing few alphanumeric characters of a license plate number could be done without internet or satellite connection.
- Other supplementary information could be typed in, later, when the driver is in the comfort of his/ her office or home and with a good network and internet connectivity to find and send the information to the database of law enforcement agencies or service providers.

Section 3 is subdivided into two *subsections* to provide a broad view of the T2T app framework: 3.1. Architecture and data flow; 3.2. Operational data flow during usage of the STT-based app in resource constrained situations, as an aid to CRP.

3.1. Architecture and Data Flow

A high-level architectural data flow is shown in Figure 1, when there is a good network connection. The STT-based mobile app is interfaced with a web app to push data to the central server. The app gets a GPS location from the place where it was last connected to the network for STT converted file. If other data is updated later once the user reaches a new location with a strong network, then data will be replaced with a new GPS location's longitude and latitude.

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Figure 1: An architectural diagram shows how data will be stored and will flow from users to the central database and back when there is a good network connection [33].

Figure 2 shows the data flow of the web version of the app with Rest-ful-API, which would buffer the data during poor or no-network. The web version of the T2T app was installed on Apache Tomcat with JBoss data services and hibernate support. Data to the central database updated via cookies enabled sessions, using (*Representational State Transfer*) *REST-ful* web services. When the wi-fi network was available, it would use SQL DB Helper *DAO* (*Data Access Object*) model; otherwise, it used the hibernate *DAO* model. The web application interacted via jQuery Ajax to call REST-ful services, which in turn would insert the data in central DB via a hibernate query. HTML5 markups and bootstrap would display the formatted data [33].

The web version of App has enriched 'User Interface' to work with various screen sizes. The T2T app allowed users to log in with their Google or Facebook account, via C-API (connector application programming interface). It fetched their public fields, such as name, gender, user id, etc. an example code of which can be referenced at the link [34].

Figure 2: An architectural diagram is showing how data is stored and flows with and without a network connection and with third-party API. Rest-ful services helps to keep the data in the buffer when there is no network in RCS. When a strong network connection is established, they push the data to the central server and free up the buffer memory.

3.2. Operational Data Flow During the Usage of the STT-based App in Resource Constrained Situations (RCS) as an Aid to CRP

For lodging a complaint against RD, the essential requirements are a) the license plate number of the vehicle b) name of the state where the incident has happened along with the date, time, and a rough geo-location. The users were able to record and store up to 50 characters of license plate number or other data in each *. JSON (JavaScript Object Notation) file via regular or Bluetooth-enabled microphone. Test users could speak out loud the license plate number of the vehicle and record the relevant details even when there was no mobile network and battery, or memory of the device was running low. There was no need to touch the device if one was using a smartwatch, Bluetooth-enable microphone, or any hands-free device. Thus, the STT-based app like 'T2T' could be used as a tool to aid CRP in resource constrained

situations against reckless driving. Please see Figure 3a and 3b for T2T App's details and operational activity data flow. The functionality of the mobile app 'T2T' is based on Android studio code, an example of which can be found at the link [35].

Figure 3a: T2T app after it expanded on a Samsung android mobile phone screen. It shows display boxes and buttons for writing license plate numbers and comments text. Figure 3b: Activity Task Diagram, showing data flow steps of a test-driver takes who tries to report a reckless driver, using STT-based app 'T2T' as an aid to CRP, during a test drive, in a Resource Constraint Situations (RCS).

Based on the database of vehicle registration and 'Vehicle Identification Number', license code patterns, law enforcement agencies can identify the owner of the vehicle. They can find out the rest of the details about the driver in question from the owner of the vehicle and can issue a ticket if the driver is found to be at fault, based on other corroborating evidence. Color, make, the model of the vehicle, photo/ video of the incident, etc. are supplementary information. For the purpose of replication, the next section focuses on experiments and usability measurements of the app.

4. Experimental Procedures

For the convenience, cost, and time effectiveness perspective, we used expert/ judgment sampling method so that we could use the expertise of selected experienced subjects/ experts

to represent the response of a bigger unknown population, which was beyond the available resource limit of the project. Judgment sampling is not always preferred but is conceptually and technically the most recommended approach to select useful samples who know about the process and their impact over a longer period [36]. We assumed that an expert user/ tester would represent a response of 10-15 non-expert users. Therefore, the quality of the survey response from a population of 200 experienced drivers with the experience in the usage of dash-cams and mobile apps can be equivalent to about 2000-3000 people without such experience.

For experimental tests, we engaged a sample population of 50 participants. Most of them were either testers or business users or fresh developers or interns. The average age of participants was 22.3 years (SD = 4.28). There were twenty-one males (42%) and the remaining female (58%) participants. The participants could speak in the English language well but were not native English speakers. All 50 test users agreed to allow recording of speech and the video and signed the '*Privacy Consent Form*' (PCF).

The overall experiment and test are presented in 4 subsections. 4.1. Functional usability test of the app on the model of the System Usability Scale (SUS); 4.2. Reliability test of the app for checking error rate in the STT conversion, in RCS; 4.3. Overall usability of the app on the SUS scale; and 4.4. Field driving testing in real Resource Constrained Situations (RCS).

We prepared ten experimental cases on the model of the SUS usability scale, to test the comparative functionalities of the app [37]. We made one question for each experimental situation and asked users to mark their rating on 5 points Likert, before switching to the next experiment. *Even-numbered experimental items* 2, 4, 6, 8, and 10 are *inverted questions* and are scored as 5 minus the scale position. *Odd-numbered experimental items* 1, 3, 5, 7, and 9 are *direct questions* and are scored as scale position minus 1. The total score of each user was multiplied by 2.5 to obtain the overall SUS scores in the range of 0 to 100 [33].

The test installation set up of the app can be requested by writing an email to copyright holder mentioned in GitHub [38]. It is loaded to Git Hub. We analyzed and interpreted the results on the model of the SUS score interpretation guide [39].

Before the experimentation, we gave a printed copy of sheets of the experimental questions to the group of 50 users, explained to them the scoring pattern, and briefed them on how the app would work. We asked the test users to check if their smartphone was converting their STT in offline mode. To do so, we asked them to connect to local wi-fi and speak 50-character dummy license plate numbers with the name of the place, i.e., 'mh01-1aa887766 and geolocation Mumbai, Maharashtra, India'. We then asked them to switch off wi-fi and put their mobile in airplane mode and repeat the above dummy license plate number and geolocation and note down the number of inaccurately converted letters.

To calculate *Word Error Rate (WER)*, we asked users to note down the number of I = inserted, D = deleted, S = substituted, and C = correct letters out of above 50 letters, spoken above [40]. If there was an issue in the STT conversion in offline mode due to the model of the phone or language accent of the user, that was taken care of by replacing the phone and allowing some orientation practice.

4.1. Functional Usability Test of the App on the Model of the System Usability Scale (SUS)

We performed this test to ensure that the STT-based app like 'T2T' is usable to check the hypothesis as mentioned in the abstract that 'STT-based apps can aid the CRP in resource constrained situations (RCS).

4.1.1. Functional Usability Experimental Case 1

Was it easy to install and set up the app?

We had checked user's smartphones if they were capable of converting STT in offline mode. We then asked users to connect to the local wi-fi network, download the complete installation set up of the app from a web link to get it installed on their smartphones. We asked users to rate the ease of installation, as compared to other apps they use, on the scale of 1-5 (1 means I strongly agree that installation of the T2T app is easy and 5 means I strongly disagree).

4.1.2. Functional Usability Experimental Case 2

Was it difficult to login through Google account?

To check the login functionality of the app to login via google API, after the installation was complete, we requested the users to sign up via their google account and create their user profile to store their data on the server database. We then asked them to compare the response time with the response time of other apps when they login to other apps via google account.

We asked users to rate the response time, on the scale of 1-5 (1 means I strongly agree that the app was very slow to login via google account and took longer than expected time and 5 means I strongly disagree).

After installation and test users' profile creation steps were completed, we asked users to sign out, put their *mobile phone on airplane mode, and disable wi-fi* on those phones. Then further experimentations were performed, as follows:

4.1.3. Functional Usability Experimental Case 3

Was the visual clarity and alignment of the app on the mobile's screen okay after it loaded on a single tap of the T2T icon?

We asked the users to check if the visual clarity of the T2T app after it expanded on the mobile screen on a single tap of the 'T2T' icon. We asked to make sure that the screen was not truncated on the sides, clear enough, and well-aligned for use on the mobile screen, as shown in Figure 3a.

We asked users were to rate this feature on the scale of 1-5 (1 means I strongly agree that the app's visual clarity and alignment were okay to make it usable and 5 means I strongly disagree).

4.1.4. Functional Usability Experimental Case 4

Was it difficult to load the app on the mobile's screen after a single tap of the T2T icon?

To test this functionality of the app, we asked users to single-tap the 'T2T' icon to load the app and expand it for use on their mobile screen, as shown in Figure 4.

Figure 4: Shows T2T app icon and actual text converted through google Speech-To-Text (STT) converter, in offline mode.

We asked users to rate the loading time as compared to the average loading time of other apps they use, on the scale of 1-5 (1 means I strongly agree that the app was struggling to load and took longer than expected time and 5 means I strongly disagree).

4.1.5. Functional Usability Experimental Case 5

Was it convenient to tap the 'License text box,' change the converted text and save with a tap of the 'save' button in the RCS of no internet?

To test this functionality of the app, we asked users to tap the 'update' button of the app to make the 'license text box' editable. Then tap on the app's the 'license text box' to edit the text via a virtual keyboard and then tap the 'save' button of the app to save the edited text and disable the editing of the 'license text box.' We then asked users also to verify that after tap of the app's 'save' button, the 'license text box' becomes non-editable. We did this to

preserve the authenticity of the text because each *lpn*.json* file is stored with a date and time stamp, in the format of 'lpn.latitude.longitude. date and time format of the mobile user's profile.Json,' on press of save button. We asked users also to open the app's '*license plate (LPN) number folder*,' tap the latest updated *lpn*.json* file, as shown in Figure 5, and make sure that it showed the same text as shown in the 'license plate box' of the app, in Figure 3b.

Figure 5: This figure shows an example of a license plate number file, stored in the license plate folder of the T2T app, in the format of LPN.lat.lng.dd.mm.yyyy.hh.mm.ss.Json.

We then asked users to compare the app's '*license plate box*' text editing functionality with regular text editing functionality of the phone and rate the comparison on the scale of 1-5. (1 means I strongly agree that it was convenient to tap the 'license text box,' change the converted text and save with a tap of the 'save' button, in the RCS of no internet, and 5 means I strongly disagree).

4.1.6. Functional Usability Experimental Case 6

Was it difficult to tap and input text in the 'comment text box,' of the app, save with a tap of the 'save' button of the app, in the RCS of no internet?

To test this functionality of the app, we asked users to tap the '*update*' button of the app to make the '*comment text box*' editable then tap the app's '*comment text box*' to edit the text via virtual keyboard. Then tap the '*save*' button of the app to save the edited text and disable the editing of the '*comment text box*.' We asked users also to verify that after tap of the app's '*save*' button, the '*comment text box*' becomes non-editable. We did this to preserve the authenticity of the text because each *cmnt*.json* files are stored with date and time stamp.

We then asked users also to open the app's '*comment text folder*,' tap the latest updated *cmnt*.json* file, as shown in Figure 6, and make sure that it showed the same text as shown in the '*comment text box*' of the app in the upper left corner of the expanded app screen, as shown in Figure 3a.

Then we asked the users to compare the app's '*comment text box*' text editing functionality with regular text editing functionality of their smartphone, rate the comparison on the scale of 1-5. (1 means I strongly agree that it was difficult to tap the '*comment text box*,' change the converted text and save with a tap of the '*save*' button, in the RCS of no internet, and 5 means I strongly disagree).

cmnt.12202019

Name

cmnt.lat.19.1024N.lng72.9200E.122019.121645.Json

cmnt.lat.19.1024N.lng72.9200E.122019.122055.Json

Figure 6: This figure shows an example of a comment text file, stored in the comment folder of the T2T app, in the format of cmnt.lat.lng.dd.mm.yyyy.hh.mm.ss.Json.

4.1.7. Functional Usability Experimental Case 7

Did you feel confident to use the app to send the license plate number and comment text?

To test this aspect of HCI, we asked the test users to connect to a local wi-fi network and tap on the 'send' button of the app. On tap of the 'send' button, the app is expected to sort lpn*.json and cmnt*.json files in the app's 'license plate folder' and 'comment text folder,' respectively, by date and time stamp. Then pick the files created or updated in the last 3 days from the current date and move them to the central server for storage and delete those files from the folders to free up space. If there is either lpn*.json or cmnt*.json file or both, created or updated in last 3 days in those folders, then it would a *warning message was pop up*; 'Do you agree to send the IP address of your device, geo-location, captured text data from this app to the central server?'

In this experimental scenario, since lpn*.json and cmnt*.json files were created and local wi-fi connectivity was available, on confirmation of the warning message mentioned above, the files moved to the database of the central server and could be verified by the web administrator, in the user's profile folders.

After the web administrator verified lpn*.json and cmnt*.json files in a few user's profile folders, we asked users to tap on the 'send' button of the app again. This time users got a pop-up warning message: 'There is no file to send. Do you want to proceed?' because lpn*.json and cmnt*.json files had moved to the central server, and the 'License plate folder' and 'comment text folder' did not have any lpn*.json or cmnt*.json file created or updated in last 3 days. On confirmation, the app came to its normal display status on the mobile's screen, as expected.

Then we asked the users to rate their confidence level in the usage of the app to send the license plate number and comment text in the RCS on the scale of 1-5. (1 means I strongly agree that I felt confident when I could send the license plate number and comment text from the app and 5 means I strongly disagree).

4.1.8. Functional Usability Experimental Case 8

Did you feel anxious to pair your Bluetooth-enabled hands-free device via the T2T app?

Before testing this scenario, we asked users to pair their smartphone with their Bluetooth microphone from the Bluetooth setting area of the smartphone and note down the time it took to complete the pairing. Then asked the users to unpair their Bluetooth-enabled microphone and pair the T2T app from the Bluetooth setting area, note down the time it took to complete the pairing. After pairing, the app is supposed to use the standard Bluetooth API of the device to interface with the microphone port of the smartphone to convert STT.

Then we asked users to rate their difficulty and anxiety level in pairing the T2T app with Bluetooth of the smartphone on a scale of 1-5 as compared to the pairing of their phone with the regular Bluetooth microphone. (1 means I strongly agree to have felt anxious in pairing my Bluetooth-enabled hands-free device via the T2T app and 5 means I strongly disagree).

4.1.9. Functional Usability Experimental Case 9

Did you feel comfortable to use the T2T app, for CRP, in reporting against reckless drivers, in the RCS when all the numbers, text, buttons functioned with ease?

By the time this aspect of the app was to be evaluated, users had experienced the functioning of almost all buttons and boxes of the app.

So, we asked users to rate the overall comfort level in the usage of the T2T app, in reporting against reckless drivers, as an aid to CRP, in RCS on the scale of 1-5. (1 means I strongly agree that the app's number, text, and buttons were easy to operate that caused me to feel comfortable to use the T2T app, for CRP, in reporting against reckless drivers, in RCS and 5 means I strongly disagree).

4.1.10. Functional Usability Experimental Case 10

Was it difficult to close the T2T app with a single tap of the 'home' button of the smartphone, that caused you to feel anxious about not being able to use your phone for other functions, in normal situations?

To test this aspect of HCI of the T2T app, we asked the test users to single-tap the 'home' button of their smartphone while the app was loaded, and its expanded screen was visible on their mobile's screen.

We asked users to rate their anxiety level in the closing of the T2T app as compared to their anxiety level in the closing any other new app on the scale of 1-5. (1 means I strongly agree that it was difficult to close the T2T app with a single tap of the 'home' button of the smartphone, and 5 means I strongly disagree).

4.2. Reliability Test of the App for Checking Error Rate in the Speech-To-Text (STT) Conversion, in RCS

Since accuracy in STT conversion is very critical for the app, we tested and measured Word Error Rate (WER) in the following manner and plotted on a graph in comparison to the STT accuracy of android phones in an offline mode.

We once again asked users to make sure that their phone is not connected to a mobile network or wi-fi. We then asked them to pair their smartphone with their Bluetooth microphone from the Bluetooth setting area of the smartphone and speak the same 50 character dummy

license plate number with name of the place, i.e., 'MH01-1AA887766, and geolocation Mumbai, Maharashtra, India', as spoken before installation of the app. We also asked them to note down the number of *I*= inserted, *D*=deleted, *S*=substituted, and *C*=correct letters out of 50 letters. STT conversion of punctuation marks such as commas, full stop, etc. was ignored for WER calculation.

Table 1: Comparative average Word Error Rate (WER) score and standard deviation of 50 users via the T2T app and their android smartphone for Speech-To-Text (STT) conversion.

WER comparison of smartphone and T2T App	WER Score	Wer*100 = Score in %
Mean WER score, using offline STT functionality of an android smartphone	0.0488	4.884
Mean WER(app)score via the T2T app	0.05	4.924
Std. Dev. of WER score, using offline STT functionality of an android smartphone	0.0205	2.0464
Std. Dev. of WER(app) score via the T2T app	0.0219	2.1895

■ STT conversion WER of Android smartphone
■ STT conversion WER via T2T app

Figure 7: Comparative word error rate (WER) of 50 users via the app and their android smartphones displayed on a boxplot graph. The X-axis represents 50 test users, and Y-axis represents the WER score in %.

After compiling *S*, *D*, *I*, and *C* values of the smartphones and that of T2T app, the WER of the app '*WER(app)*' was calculated with the following formula:

$$\text{WER(app)} = (S+D+I) / (S+I+C)$$

WER(app) and WER of android smartphones multiplied by 100 for better rounding of decimal and present in percentage form. The average/ mean and a Standard Deviation of the WER score of 50 users is given in Table 1 and plotted a graph, as shown in Figure 7.

4.3. Comparison of the Response of Test Users on Ten Experimental Cases Vs. On the SUS Scale

At the end of the ten experimental scenarios, and testing of *Word Error Rate* (WER), we gave the users sixty minute's break and then presented with actual SUS survey questions to get the overall usability of the app. Experimental scores of the above ten experimental cases were recorded, normalized, and the results are presented below in summarized tables and graphs.

Table 2: Comparative mean score and standard deviation of 50 test users on the standard SUS scale and on the scale prepared for 10 experimental cases designed on the model of the SUS questions.

Description of Rating scale score	Value
Mean on the original SUS rating scale	71.56
Mean on the scale prepared for 10 Experiments	71.12
Std. Dev on the original SUS rating scale	3.098123
Std. Dev on the scale prepared for 10 Experiments	2.79679

Figure 8: Clustered column line graph showing a comparative mean score of the SUS rating in blue columns and rating of the SUS modelled experiment of the T2T app, in orange line. The X-axis represents 50 test users, and Y-axis represents mean SUS and SUS modelled Experimental score.

The average/ mean and standard deviations of the response score on the SUS scale and that of the ten experimental cases prepared on the model of the SUS scale are presented in Table 2 and plotted on a clustered column line graph, as shown in Figure 8. We could have plotted the score comparison on a boxplot but preferred to use a clustered column line graph, instead to display a better visual of the mean score, user-wise.

To make the scoring easy, we converted the ten *Experimental Questions* (ExptQ1 to ExptQ10), prepared on the model of SUS scale and presented in the following statement format, so that users could easily rate on 5 points Likert scale, as shown in Table 5, in Appendix A4.

4.4. Field Driving Testing in Real Resource Constrained Situations (RCS)

Three simulated field testing were conducted to gauge the confidence level of the users, in reporting against reckless drivers. These were done on 3 sample populations of 50 unaccompanied drivers in 3 different geographical settings in three different cities, in 3 groups of 10, 20 and 20. These 50 test drivers had 'T2T' app installed on their mobile device and they used it while driving and their experience was recorded via '5-Question survey' they responded to.

Figure 9: This cumulative columnar bar graph displays the response of 50 experienced drivers for the 5 Question Survey, post driving and use of STT-based, 'T2T' app, in *resource constrained situations*, to evaluate the effectiveness of the STT-based app like 'T2T', as a tool for CRP, in RCS. The X-Axis shows Survey Question (1 to 5). The Y-Axis displays the cumulative number of users who have responded on the Likert from strongly agree to disagree strongly.

The first field test was conducted in Kalamazoo county of Michigan, USA. Second, field testing was done in Lonawala – hilly area between Bombay and Pune in India. The third field experiment was done on the outskirts of Nashik city near river Godavari in Maharashtra, India. These test areas have many spots where there is no mobile network availability for a certain mobile network or their operators, especially for certain MVNOs (mobile virtual network operator). Testers could use STT via the T2T app to record number plates. Videos of the experiment were recorded for survey purposes. All 50 experienced drivers had agreed to allow recording of speech and the video and signed the PCF. These drivers were given a quick 5 question survey at the end of driving. The questions are mentioned below in Table 3, and the

responses of 50 experienced drivers are plotted in a cumulative columnar bar graph, as shown in Figure 9. The data flow, as shown in Figure 2 was more representative during field testing.

Table 3: Five Survey questions to evaluate the effectiveness of the STT-based, T2T app as a tool for CRP in real Resource Constrained Situations (RCS).

- 1) Using a device like Alexa voice-enabled Garmin dash-cams was distracting during driving because of frequent disconnections, in poor network areas.
- 2) After using the STT-based T2T app, my confidence level in reporting against RD, in RCS, has gone up.
- 3) I would recommend using a simple STT-based app in RCS to report against RD.
- 4) Speech-To-Text (STT) based apps/devices consumes less memory and less battery power, in RCS.
- 5) STT-based apps/devices would be more convenient to use, in RCS, to report against RD than video-based technology as an aid to CRP.

5. Video-Based Survey and Responses after the Experiments

Table 4: Ten Survey questions to evaluate the effectiveness of STT-based app as an aid to CRP in Resource Constrained Situations (RCS) to report against Reckless Driving (RD).

- 1) After watching the videos, I felt more confident to use STT-based app as an aid to CRP as compared to IVMS devices, in RCS, to gather information about RD.
- 2) As per the results in the videos, the STT-based apps appear as a reliable and usable tool to help CRP in RCS.
- 3) CRP, when aided with STT-based apps, would be more effective in reducing RD, as compared to many IVMS tools, in RCS.
- 4) To avoid being distracted by a new STT-based apps, I would prefer to use my regular dash-cam or app even if it performs poorly, and data quality is compromised in RCS.
- 5) For convenience purposes, I would prefer the usage of IVMS devices for gathering information about RD, even if it performs poorly, and data quality is compromised in the RCS.
- 6) Existing CRP don't need STT-based apps in reducing RD if there are no resource constraints.
- 7) Existing IVMS options are enough in reducing RD if there are no resource constraints.
- 8) IVMS devices would be less distracting than CRP options in RCS.
- 9) There are fewer data privacy concerns in the usage of STT-based apps as an aid to CRP than in the usage of IVMS devices.
- 10) There are more data privacy concerns in the usage of STT-based apps as an aid to CRP than in the usage of IVMS devices if CRP data is crowdsourced.

Figure 10: This cumulative columnar bar graph displays the response of 200 experienced drivers for the Video-based Survey questions to evaluate the effectiveness of STT-Based app as an aid to Citizen Reporting Program (CRP) in Resource Constrained Situations (RCS). The X-Axis shows Survey Question (1 to 10). The Y-Axis displays the cumulative number of users who have responded on the Likert from strongly agree to disagree strongly.

Four video-based surveys were conducted in 4 cities mentioned in subsection 4.4, i.e., Kalamazoo, Bombay, Pune, and in the city of Noida-India's national capital region (NCR). The sample population consisted of 200 experienced drivers, in groups of 50 people, who had experience in the usage of dash-cams and mobile apps. The median (MD) age of participants was 37.3 years, with a standard deviation (SD) of 3.48. There were 140 males (70%) and the remaining 60 female (30%) participants. Thus, the survey population of 200 drivers with previous experience in the usage of dash-cams, was fairly diverse in terms of socio-economic, cultural, and linguistic backgrounds. We explained the experimental details to the users and then showed the video recorded for tests for functional usability, WER, and road field in RCS. They responded to the ten survey questions, as shown in Table 4, on a 5-point Likert scale to evaluate the effectiveness of STT-based app like 'T2T' as an aid to CRP in RCS. The cumulative columnar bar graph, as shown in Figure 10, displays the survey results. For privacy reasons and to protect the identity of the testers, the video clip of the recorded test used for this survey is not being made public but may be received from the project sponsoring organizations, as per the terms mentioned in PCF.

6. Analysis of Experimental Results and the Survey Responses

6.1. Analysis of the WER test Results

1. In general, WER of less than 5 percent is acceptable. As per Table 1, the WER(app) and WER of android smartphones are very close. The WER(app) score of 4.924 with a standard deviation of 2.1895 for the app indicates that the app's STT conversion functionality is in the acceptable range.
2. Comparative WER of 50 users, as shown in the boxplot of Figure 7, has a standard deviation of 2.1895. It may be due to user-specific fluctuation in Speech-To-Text (STT) conversion. Probably accent in speaking English language, voice, a tone played a role. It means, with some training and practice, the errors can be reduced, but there can also be *cultural and linguistic interference* in the HCI framework. Therefore, more experiments may be required in the future for using the app in other languages.

6.2. Analysis of the Results of the Functional Usability Test of the STT-based app like 'T2T' as an aid to CRP, in the Context of Resource Constrained Situations (RCS), on the Model of the System Usability Scale (SUS)

- The SUS score between 70 and 80 is better than the average [39], [41]. As per Table 2, the SUS score of the app is 71.56, with a standard deviation of 3.098123. The rating score of 10 experimental cases modeled on the SUS scale has a value of 71.12, with a standard deviation of 2.79679. Both the results point that the app's functionalities and performance are in an acceptable range, though overall usability was rated higher. It also points towards the possibility of improving the app's usability by enhancing some of its functionalities.

- Comparative SUS score and the rating score of 10 experimental cases modeled on the SUS scale, as shown in the Clustered column line graph Figure 8, indicate that fluctuation in the score was user specific. In other words, the users who scored higher on the SUS modeled experiment scored high on SUS usability also. This points towards the usability rating as a dependent even on how techno-savvy are the users or how efficient their smartphones are. This means, with some training and practice, the scores can be improved.

6.3. Analysis of the Results of the Field Driving Testing in Real Resource Constrained Situations (RCS), for the STT-based app as an aid to Citizen Reporting Program (CRP)

As per the response data shown in Figure 9, the following inferences can be drawn:

6.3.1. 86% of the test drivers either strongly agreed or agreed that using a device like Alexa voice-enabled Garmin dash-cams was distracting during driving because of frequent disconnections, in poor network areas.

6.3.2. 80% of the test drivers either strongly agreed or agreed that after using the STT-Based T2T app, their confidence level in reporting via CRP, against RD in RCS went up.

6.3.3. 70% of the test drivers either strongly agreed or agreed that they would recommend using an STT-Based app in RCS to report against RD, as an aid to CRP.

6.3.4. 86% of the test drivers either strongly agreed or agreed that STT-based apps/devices consume less memory and less battery power in RCS.

6.3.5. 76% of the test drivers either strongly agreed or agreed that STT-based apps/devices would be more convenient to use as an aid to CRP, in RCS to report against RD than video-based technology.

6.4. Analysis of the Results of the Video-Based Survey after the Experiments for Evaluating Effectiveness of STT-based app as an aid to Citizen Reporting Program (CRP) in the Context of Resource Constrained Situations (RCS).

As per the response data shown in Figure 10, the following inferences can be drawn:

6.4.1. 155 (77.5%) of 200 test users either strongly agreed or agreed that after watching the videos, they felt more confident to use STT-based app as an aid to CRP as compared to IVMS devices, in RCS, to gather information about RD.

6.4.2. 140 (70%) of the 200 test users either strongly agreed or agreed that STT-based apps appear as a reliable and usable tool to help CRP in RCS.

6.4.3. 143 (71.5%) of the 200 test users either strongly agreed or agreed that CRPs, when aided with STT-based apps, would be more effective in reducing reckless driving, as compared to many IVMS tools, in RCS.

6.4.4. 96 (48%) of the 200 test users either strongly agreed or agreed that to avoid being distracted by a new STT-based apps, they would prefer to use regular dash-cam or other apps even if it performs poorly, and data quality is compromised, in RCS. It means if they are more familiar with the new apps, they may get less distracted, and the % of testers favouring IVMS as an aid to CRP, in RCS, can go further down.

6.4.5. 88 (44%) of the 200 test users either strongly agreed or agreed that for convenience purposes, they would prefer the usage of IVMS devices for gathering information about RD, even if it performs poorly and data quality is compromised, in the RCS. It means devices and apps designed to function in RCS, for CRP must be made more convenient for mass usage.

6.4.6. 114 (57%) of the 200 test users either strongly agreed or agreed that existing CRP options are enough in reducing RD if there are no resource constraints. It means options for CRP are slowly reaching a saturation point in developed countries where there is no resource constraint.

6.4.7. 124 (62%) of the 200 test users either strongly agreed or agreed that existing IVMS options are enough in reducing reckless driving if there are no resource constraints. It means

IVMS options in reducing reckless driving are reaching a saturation point at a much faster pace in developed countries, where there is little to no resource constraint.

6.4.8. 98 (49%) of the 200 test users either strongly agreed or agreed that IVMS devices would be less distracting than CRP options in RCS. It emphasizes that tools that aid CRP need to be more convenient, even in RCS.

6.4.9. 126 (63%) of the 200 test users either strongly agreed or agreed that there are less data privacy concerns in the usage of STT-based apps as an aid to CRP options than in the usage of IVMS devices. It means that users have more confidence in the usage of STT-based apps as an aid to CRP from a data privacy perspective.

6.4.10. 133 (66.5%) of the 200 test users either strongly agreed or agreed that there have more data privacy concerns in the usage of STT-based apps as an aid to CRP options than in the usage of IVMS devices if CRP data is crowdsourced. It means people are less inclined to crowdsource their data related to CRP unless there is a strong data protection process and procedures in place.

7. Discussion on Implementation, Challenges, Possible Solutions and Opportunities

Like any other novel framework, the effort to reduce reckless driving via CRP with the aid of any new STT-based app could face a few challenges in implementation and open some opportunities, as discussed below.

Adaptation Challenges

An STT-based app would aid Citizen Reporting Program (CRP) in reducing reckless driving, in RCS but it would also require support from the law enforcement agencies, such as the association of attorneys or lawyers and local police department, for its widespread implementation, awareness campaign and public participation. It would require an agreement for collaboration between service providers, private companies, and other relevant government agencies to align their CRP, existing software applications, along with user training as well as testing for proper implementation and support.

Privacy Challenges

Confidence-building about users record collection methods, trust in the company, faith in the police, trust in the amount of data an app would gather, during CRP, about IP address of the device, and geolocation of the user could be a challenging task. Encrypting the data and concealing the source of information to viewers other than the reporter and relevant authorities would help build trust and confidence. The collaboration amongst law enforcement agencies, private and public participation would be required to be developed to maintain this delicate balance.

Data Quality Issue, False Alarm, or Misuse

Many times, the quality and relevance of data such as license plate number, text, etc. is not very helpful in verifying the RD behavior because the vehicle record was not proper or there was an ill intention of its usage. The reporting person may misinterpret some behavior because of socio-cultural or other human factors. There have been some cases of smartphones and dashcams being misused. It would require some adaptation time and coordination amongst various interest groups, i.e., local agencies which are involved in appropriate CRP.

Training and Awareness Challenges

In many countries, ordinary citizens are scared of participating in CRP for the fear of being harassed by law enforcement agencies. In some developing countries, a vehicle is registered at the time of the first sale and hardly afterward [42]. People, especially in developing countries, need to be aware of available tools, be trained to work on open government concept with law enforcement agencies, and timely registration of the vehicles, especially when ownership of the vehicle is transferred.

Weather or Situational challenge

There may be poor light or bad weather, which may hamper the accuracy of the gathered data for CRP. A bicyclist may have a hard time reading number plates or recording videos in low-light situations because of the difference in speed between the vehicle and the bicycle. But it is not impossible to use the app in many cases, or if the reckless driver is a local and repeats the behavior, then the bicyclist can be alert and ready to record the next day. However, if the driver/bicyclist/pedestrian is alert, he/she may use a smartwatch, Bluetooth enabled microphone/ hands-free device to record the license plate number of the risky driver.

The challenges and opportunities mentioned above would apply to almost all new apps and devices that can be used to aid CRP; however, the STT-based apps like T2T can make certain additional contributions in the future as discussed below, which we did not find with many similar apps.

Possible Contributions of the STT-base app like ‘T2T’ to the Future, for CRP in Resource Constrained Situations (RCS)

There are many web-portal reporting services offered by many professional agencies that can provide accident history and profile of vehicles based on number plates or ‘*Vehicle Identification Number*’. Thus, the STT-based HCI framework of an app like ‘T2T’ may help those prudent users who want to search and evaluate the profile of risky drivers via their recorded license plate number, in RCS, before lodging complaints against them [43].

The ‘T2T’ app may be coded to take pictures of the license plate number in RCS and convert them into structured text data. People may be able to use the web version of the app so that they can choose a pre-defined list of violation types. These violation types would be stored in SQLite database (DB) and would be sent to the main server along with timestamp as and when a connection to the internet would be available. If heavy images or short videos are to be uploaded, that would be organized in image/video directory on webserver to avoid load on the database.

There is a high possibility that the data gathered in RCS, can contribute to crowdsourced data and be helpful to law enforcement agencies for relevant CRP. They would verify the authenticity of the data and work with concerned parties to collect additional information to corroborate the pieces of evidence.

8. Conclusions and Perspectives

Based on the information analysis and the review of relevant literature and reports of the organization such as NTHSA, United Nations, it was observed that Police Per Thousand Residents (PPTR) has been declining, and law enforcement agencies are slowly encouraging more people to participate in Citizen Reporting Programs (CRP) to safeguard fellow citizens by providing evidential information to law enforcement agencies in detecting the reckless drivers and getting them corrected.

It was determined that there is a niche area which represents people such as unaccompanied drivers, bicyclists, pedestrians, especially in developing countries, who get stuck on either busy roads or secluded places like mountain, valleys, dessert, with a low battery, low device-memory, and no mobile network but need to report against reckless drivers, effectively.

Review of IVMS devices, Dash-cams, and relevant websites mentioned above indicate that there are many data gathering apps, tools, and gadgets available, but most of them require large memory storage, strong mobile signals, unlimited internet, high bandwidth of data usage, a co-passenger or specialized devices. They do not entirely fulfill the requirement of the above Resource Constrained Situations (RCS). However, their data would be beneficial in supplementing the information gathered in RCS by the STT-based mobile apps like T2T for CRP. External feedback and triggers received from people would help to investigate already available data from IVMS to start taking more targeted corrective actions, e.g., issuing tickets, training, incentives/disincentives, suspension of a driver's license, etc.

The Architecture, design, flow diagrams, code logic, the functional, operational, and economic utility of the STT focused app like T2T was compared, reviewed, tested, and evaluated for CRP in RCS. With the WER of less than 5% and a usability score of more than 71%, the T2T app has a high potential to be used as a reliable STT-based tool for CRP in RCS.

CRP could be more effective when data recorded by STT based apps like T2T is supplemented with crowdsourced data recorded via other methods to help law enforcement agencies and to discourage distracted as well as reckless driving [44]. The data could be encrypted with date, time, location, and other information required to issue a ticket and then be uploaded to a server. The records could then be reviewed and approved by law enforcement agencies who would have the final authority to issue the ticket.

It can be inferred from subsection 6.3 that the majority of the test drivers (more than 70%) would favor STT-based apps/devices over video-based technology, for CRP, in RCS to report against RD, though they wanted it to be more convenient to use. In summary, it can be inferred from subsection 6.4 that there is strong potential for STT-based apps helping CRP to reducing reckless driving in RCS. It is also important that more convenient and user friendly STT-based apps become, the more widespread it is implemented as an aid to CRP, the larger will be the domino effect. Then reckless drivers would realize that lodging complaints against reckless driving would be easy, even in resource-constrained situations like crowded or secluded places by an unaccompanied person without mobile network. This implies that STT-based Apps can

make a good psychological and behavioral impact on risky drivers. Therefore, STT-based Apps have a good potential to aid CRP in reducing reckless driving in resource constrained situations.

9. Data Availability

The data used to verify the findings of the experiments of this paper are available from the corresponding author upon request. The set-up code for the T2T app can be found at Git Hub, subject to permission from sponsoring organizations “see link at reference [38] for more details.”

10. Conflicts of Interest

There is no conflict of interest regarding the publication of this paper.

11. Funding Statement

This work was supported in part by a joint pilot project with the Department of Motor Vehicles, Government of Maharashtra, India, under project number MORTH1.2018.prjt.875”. However, this article is not funded by any organization.

12. Acknowledgments

The authors are very thankful to the anonymous reviewers and colleagues who provided insightful thoughts, valuable suggestions, and encouragement. The authors are also grateful to Ms. Jo Quintanilla, University of Sydney, Australia, a digital project manager by profession and Ms. P. Singh, Bombay University, India, for organizing information and proofreading the papers. The authors remain the only person accountable for any omissions or mistakes.

13. Supplementary Materials

See Figures 1-3, Piccolo Plus In-vehicle interfaced On-Board-Device and other related information, in the supplementary video for more vivid details.

Appendix A

A1

- Dial 911 in USA/Canada/ Brazil/ Bahamas/ Bermuda,
- Dial 100 (India/ Greece/ Israel/ Nepal/ Turkey)
- Dial 112 (Australia/ Austria/ / Belgium/ Denmark / Bali /England/ Finland/France etc.)

A2

- National Consumer Complaint Database (NCCDB) portal is run by (FMCSA) Federal Motor Carrier Safety Administration of the USA, primarily for commercial vehicles [45].
- National Highway Safety Administration (NTHSA) [46].
- Virginia State Police complaint website [47].

- California Highway Police complaint website [48].
 - <http://www.reportdangerousdrivers.com> [49].
 - <https://licenseplaterreports.com/> [50].
- A3
- Dride Zero smart Dash-cam with the share button,
 - Securityman Dash-cam with iOS/ Android app
 - Vezo 360: 4K 360 Dash-cam with AI-powered drowsiness detection
 - Vava Dash-cam
 - Nexar
 - Garmin + amazon Alexa [51].
 - RecklessRadar.com [52].

A4

Table 5: Ten Experimental questions (ExptQ1 to ExptQ10), prepared on SUS model questions, in statement format to rate the functional usability of the T2T app on the *5-points Likert scale*.

ExptQ1. It was easy to install and set-up the app.
ExptQ2. It was difficult to login to the T2T app via Google account.
ExptQ3. The visual clarity and alignment of the app on the mobile's screen were okay after it loaded on a single tap of the T2T icon.
ExptQ4. It was difficult to load the app on the mobile's screen after a single tap of the T2T icon.
ExptQ5. It was convenient to tap the 'License text box,' change the converted text and save the texts with a tap of the 'save' button in the RCS of no internet.
ExptQ6. It was difficult to tap and input text in the 'comment text box,' of the app, save with a tap of the 'save' button of the app, in the RCS of no internet.
ExptQ7. I felt confident to use the app to send the license plate number and comment text.
ExptQ8. I felt anxious to pair my Bluetooth-enabled hands-free device via the T2T app.
ExptQ9. I felt comfortable to use the T2T app, for CRP, in reporting against reckless drivers, in RCS when all the numbers, text, buttons functioned with ease.
ExptQ10. It was difficult to close the app with a single tap of the 'home' button of the smartphone, which caused me to feel anxious about not being able to use my phone for other functions.

References

- [1] "Global status report on road safety 2018." World Health Organization, 2018, WHO/NMH/NVI/18.20. License: CC BY-NC-SA 3.0 IGO. ISBN 978-92-4-156568-4. [Online]. Available: https://www.who.int/violence_injury_prevention/road_safety_status/2018/GSRRS2018_Summary_EN.pdf
- [2] Wilms, Todd. "It Is Time For A 'Parental Control, No Texting While Driving' Phone. Forbes Business." September 18, 2012.

- [3] P. Majaranta and A. Bulling, "Eye Tracking and Eye-Based Human–Computer Interaction," in *Advances in Physiological Computing, Human–Computer Interaction Series*, pp. 39–65, Springer London, London, 2014.
- [4] Shelley Hyland, Ph.D., U.S. Department of Justice. Office of Justice Programs. Bureau of Justice Statistics. "Full-Time Employees in Law Enforcement Agencies.1997-2016." BJS Statistician, August 2018. Law Enforcement Management and Administrative Statistics survey, 1997–2016. [Online]. Available: <https://www.bjs.gov/content/pub/pdf/ftelea9716.pdf>
- [5] UNITED NATIONS, DESA / POPULATION DIVISION. "World Population Prospect 2019, age group 15-64." License: CC BY-NC-SA 3.0 IGO. [Online]. Available: <https://population.un.org/wpp/Graphs/Probabilistic/POP/15-64/900>
- [6] Richard, C. M., Magee, K., Bacon-Abdelmoteleb, P., & Brown, J. L. (2018, April). "Countermeasures that work: A highway safety countermeasure guide for State Highway Safety Offices," Ninth edition (Report No. DOT HS 812 478). Washington, DC: National Highway Traffic Safety Administration. [Online]. Available: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/812478_v5_countermeasures-that-work-a-highway-safety-countermeasures-guide-9thedition-2017.pdf
- [7] "The global dashboard camera market 2012-2020 projection." Revenue US \$Million, Year-Over-Year (YOY) % Growth. Published April 2018, Copyright: Transparency Market Research. 2015. [Online]. Available: <https://www.transparencymarketresearch.com/pressrelease/dashboard-cameras-market.htm>
- [8] Thomas W. Planek Stuart A. Schupack Richard C. Fowler, Research Department, National Safety Council, Chicago, Illinois, U.S.A. "Accident Analysis & Prevention" Volume 6, Issues 3–4, December 1974, Pages 271-297, Updated, 15 July 2002. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/0001457574900050>
- [9] Hurst, P. M. (1980). "Can anyone reward safe driving?" *Accident Analysis and Prevention*, 12(3), 217–220. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/0001457580900226>
- [10] Khaled Shaaban. Department of Civil Engineering, Qatar University. Academic Editor: Richard S. Tay. "Assessment of Drivers' Perceptions of Various Police Enforcement Strategies and Associated Penalties and Rewards." *Journal of Advanced Transportation* Volume 2017, Article ID 5169176, 14 pages. [Online]. Available: <https://www.hindawi.com/journals/jat/2017/5169176/>
- [11] Barbara Tasch, "The 25 richest countries," ranked, 2016. *Business Insider*, 31 March 2016. [Online]. Available: <http://uk.businessinsider.com/the-richest-countries-in-the-world-2016-3>
- [12] Burton, James. (2019, October 23). "The Richest Countries In The World". [Online]. Available: <https://www.worldatlas.com/articles/the-richest-countries-in-the-world.html>
- [13] Chaudhary, N. K., Casanova-Powell, T. D., Cosgrove, L., Reagan, I., & Williams, A. (2012, August). "Evaluation of NHTSA distracted driving demonstration projects in Connecticut and New York." (Report No. DOT HS 811 635). Washington, DC: National Highway Traffic Safety Administration.
- [14] Zhu, X., Hu, X., & Chiu, Y.C. "Design of Driving Behavior Pattern Measurements Using Smartphone Global Positioning System Data." *International Journal of Transportation Science and Technology*. Volume 2, Issue 4, 1 December 2013, Pages 269-288. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S2046043016300855>
- [15] PTOLEMUS Consulting Group. "Usage Based Insurance Global Study", Edition 2013. [Online]. Available: <https://www.ptolemus.com/content/uploads/2013/10/UBI-Global-Study-Free-Abstract1.pdf>
- [16] Castignani, G., Derrmann, T., Frank R., Engel, T. (2015). "Driver Behavior Profiling Using Smartphones: A Low-Cost Platform for Driver Monitoring." *IEEE Intell. Transp. Syst. Magazine*, vol. 7, no. 1, pp. 91-102. [Online]. Available: <https://ieeexplore.ieee.org/document/7014406>
- [17] Wireless Links - GPS Fleet Management Solutions. (2019). [Online]. Available: <https://wlius.com/telematics-gps-devices/piccolo-plus-gps/>

- [18] Deloitte U.K. (2013). "Deloitte research highlights consumers' attitudes to telematics." [Online]. Available: <http://www.deloitte.com>
- [19] Lemur Vehicle Monitors. (2019). [Online]. Available: <https://www.bluedriver.com>
- [20] Verizon Communications Inc. Hum by Verizon. (2019). [Online]. Available: <https://www.hum.com/products/hum-x/>
- [21] Autobrain vehicle diagnostic and tracking application and services (2019). [Online]. Available: <https://www.autobrain.com/business>
- [22] Aviva PLC. (2019). Aviva RateMyDrive. [Online]. Available: <http://www.aviva.co.uk/drive/>
- [23] State Farm Mutual Automobile Insurance Company. (2019). "State Farm driver feedback." [Online]. Available: <http://www.statefarm.ca/about/mobile/>
- [24] AXA Belgium. (2019). AXA drive. [Online]. Available: <https://www.axa.be/ab/FR/particuliers/Pages/HomeB.aspx>
- [25] GreenRoad Technologies, Inc. (2019). [Online]. Available: <http://greenroad.com/uk>
- [26] "Two Community Distracted Driving Programs Reduce Hand-Held Phone Use," DOT HS 811 867,8609-031414-v4, March 2014, National Highway Traffic Safety Administration. Available online: https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/811867_two_comm_distracted_driving_prog_reduce_handheld_phone_use_tt.pdf
- [27] Wang, J., Zheng, Y., Li, X., Yu, C., Kodaka, K. and Li, K. (2015). "Driving risk assessment using near-crash database through data mining of tree-based model." Accident Analysis & Prevention, no. 84, pp. 54-64.
- [28] McLaughlin, Shane B., Jonathan M. Hankey, and Thomas A. Dingus. "A method for evaluating collision avoidance systems using naturalistic driving data." Accident Analysis & Prevention 40.1 (2008), pp. 8-16. [Online]. Available: <https://www.sciencedirect.com/science/article/abs/pii/S0001457507000632?via%3Dihub>
- [29] Beweb Ltd. (2019). "Android system settings for speech and voice recognition." [Online]. Available: <https://speaking.email/FAQ/87/android-system-settings-for-speech-and-voice-recognition>
- [30] Apple, Inc. (2019). [Online]. Available: <https://support.apple.com/en-us/HT202584>
- [31] Jessica Thornsby. "Converting speech to text: How to create a simple dictation app." Available online: <https://www.androidauthority.com/converting-speech-to-text-voice-dictation-app-976732>. Source code Github link: <https://github.com/JessicaThornsby/SpeechToText-demo>
- [32] J. SIMPSON. "5 Best Speech-to-Text APIs," March 28, 2019. Available online: <https://nordicapis.com/5-best-speech-to-text-apis>
- [33] Singh, B.; Singh, N. "MoLaBSS: Server-Specific Add-On Biometric Security Layer Model to Enhance the Usage of Biometrics." Information 2020, 11, 308. Available online: doi.org/10.3390/info11060308
- [34] Juned Mughal, "How to get Facebook login user data ID, first name, last name, email, gender, link, locale and account verified status programmatically." May 2017. Copyright, Android-Examples.com. [Online]. Available: <https://www.android-examples.com/facebook-login-graph-api-get-user-info>.
- [35] Juned Mughal, "How to Get Current GPS Coordinates Location Android Programmatically," December 2016. Copyright, Android-Examples.com. [Online]. Available: <https://www.android-examples.com/get-current-gps-coordinates-location-android-programmatically>.
- [36] Rocco J. Perla, EdD; Lloyd P. Provost, MS. "Judgment sampling: a health care improvement perspective." Wolters Kluwer Health Lippincott, Williams & Wilkins. Q Manage Health Care, vol. 21, No. 3, page 170, 2012. DOI: 10.1097/QMH.0b013e31825e8806

- [37] Brooke, J. "SUS: A Quick and Dirty Usability Scale." (1996). In: P.W. Jordan, B. Thomas, B.A. Weerdmeester & I.L. McClelland (Eds.), *Usability Evaluation in Industry*. London: Taylor & Francis.
- [38] Nishaan "T2T app Edit Text Test", 2019. Copyright: GitHub, Inc. 2019. [Online]. Available: <https://github.com/NishaanGHac/T2TappEditTextTest>
- [39] Jeff Sauro, PhD, "ASSURING USABILITY WITH THE SYSTEM USABILITY SCALE (SUS)." February 2, 2011. [Online]. Available: <https://measuringu.com/sus/>
- [40] K. Zechner and A. Walbei "Minimizing Word Error Rate in Textual Summaries of Spoken Language". 2000, pp 187-193
- [41] Aaron Bangor, PhD, CHFP, Philip Kortum, PhD, James Miller, PhD. "Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale." *JUS "Journal Usability Study"* Vol. 4, Issue 3, May 2009, pp. 114-123. [Online]. Available: <https://uxpajournal.org/determining-what-individual-sus-scores-mean-adding-an-adjective-rating-scale/>
- [42] Jameela, M., Afzal, H., Khurshid, K. and Malik, A. "Crowdsourced System to Report Traffic Violations – Road Cop: Bi-Modular System." In *Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2018)*, Vol. 1 - 978-989-758-293-6. pages 315-322.
- [43] "License Plate Lookup." Accucom Corporation, (2019). [Online]. Available: <https://recordsfinder.com/plate/>
- [44] Kumar, A., Ross, C.L., Karner A., and Katyal R. "Crowdsourced Social Media Monitoring System Development." Publication FHWA-GA-17-1614, Report No. 16-14, 2017. [Online]. Available: <https://pdfs.semanticscholar.org/064e/7ce0ac82f4b357df05357f534d5804a16917.pdf>
- [45] U.S. DEPARTMENT OF TRANSPORTATION, (NCCDB) - National Consumer Complaint Database, portal "File a complaint against a driver." Updated as of Sept 2019. [Online]. Available: <https://nccdb.fmcsa.dot.gov/nccdb/ComplaintEntry.aspx?choice=DRIVER>
- [46] National Highway Safety Administration (NHTSA). Risky Driving. "NHTSA works to eliminate risky behaviors on our nation's roads." Updated as of Sept 2019. [Online]. Available: <https://www.nhtsa.gov/risky-driving>
- [47] Virginia State Police complaint website. "Aggressive/Reckless Driver – How to Report." Updated as of Sept 2019. [Online]. Available: https://www.vsp.virginia.gov/Aggressive-reckless_Driver.shtm
- [48] California High Way Police (CHP) complaint website. "Notify CHP." Updated as of Sept 2019. [Online]. Available: <https://www.chp.ca.gov/notify-chp>
- [49] "Report Dangerous Drivers portal." Updated as of Sept 2019, [Online]. Available: <http://www.reportdangerousdrivers.com>
- [50] "License Plate Reports Portal". Updated as of Sept 2019. [Online]. Available: <https://licenseplatoreports.com/>
- [51] Alexa plus Garmin, Updated as of Sept 2019. Available online: <https://www.amazon.com/Garmin-Alexa-Built-looping-010-01862-00/dp/B0789FRT9V>
- [52] RecklessRadar.com (August 2017), *RecklessRadar Android app*. Available online: <https://play.google.com/store/apps/details?id=com.recklessradar.mobile.application>