User-Feedback for Road Traffic Information using Mobile Phone

Jirapa Jaroenjanyakul, Wasan Pattara-Atikom, Satidchoke Phosaard, *member, IAENG,* and Weerapong Polnigongit

***ABSTRACT*—This paper presents a novel system to collect traffic data using the user feedback via mobile phone. The devices can work like the distributed human-sensors in conjunction with the cellular-based and GPS-based sensor which can collect the traffic information to the traffic report server. The congestion degrees explicitly reported by the user can be instantaneously used. Cellular-based and GPS-based data can be used alone to estimate traffic congestion conditions using congestion estimation algorithms, or can be used to cross check with the congestion degrees provided by the cell phone users. The system can operate on various levels of mobile phone specifications relying on the cell-dwell time (CDT) and the geographical positioning system (GPS). Moreover, since it runs on the mobile phone network, this traffic report system can be used to report traffic conditions on virtually all routes that the phone network reaches. This system, though conceived for use in Bangkok, is a general intelligent traffic system (ITS) module that can be applied to any part of the world. For such a system to be widely adopted, it must be user-centric, persuasive, and practically effortless to use. Thus, the usability study has been exhaustively conducted and discussed.**

***Index Terms*—intelligent traffic system (ITS), user-feedback traffic report, cell-dwell time (CDT), mobile application, mobile application usability testing**

I. Introduction

Accurate traffic reports are essential for congested and overcrowded cities such as Bangkok or even in sparse and remote areas during a long holiday period. Without these, commuters might not choose the proper routes and could get stuck in traffic for hours. Intelligent Traffic System (ITS) with automated congestion estimation algorithm can help produce such reports. Several initiatives from both private and government entities have been proposed and implemented to gather traffic data to feed the ITS. According to our survey, most efforts focus on limited installation of fixed sensors such as loop-coils and intelligent video cameras with image processing capability. However, the costs of such implementations are very high due to the high cost of the devices, installation, and maintenance. Moreover, these fixed sensors are vulnerable to extreme weather typical in certain areas. Additionally, the installation of fixed sensors to cover all roads in major cities is neither practical nor economically feasible. An alternative way to collect traffic data at a lower cost with wider coverage is therefore needed.

Recently, mobile sensors or probe vehicles appeared as a complementary solution to fixed sensors for increasing coverage areas and accuracy without requiring expensive infrastructure investment. Two popular types of mobile sensors are GPS-based and cellular-based. GPS-based sensors are sensors with GPS capability and cellular-based sensors are sensors that use information from cellular networks as traffic sensors.

Although GPS-based sensors can provide better accuracy in terms of vehicle position and velocity, cellular-based sensors are much lower in cost due to the large number of mobile phones and their associated infrastructures already in service. According to recent statistics, the mobile phone penetration rate in Thailand is expected to grow to 90% in 2009 [1]. Moreover, cellular-based sensors are less susceptible to multipath fading from skyscrapers, elevated trains, and elevated roads than GPS-based sensors.

Even though we can derive highly accurate information on the movement of a vehicle from both types of sensors, the interpretation of the data to provide congestion degrees is still a problematic task. The reason is that congestion degrees are usually influenced by several other factors including types of road, the time of day, the day of the week, and demographic factors, such as age, region, and so on. By having a large number of road users to explicitly report congestion levels via mobile phone, we can provide one of the most realistic traffic congestion reports. Mobile phone, in this way, are human-based sensors. However, use of a mobile phone *while driving* is dangerous and often illegal.

In this paper, we compensate advantages and disadvantages of the GPS-based, the cellular-based—using cell-dwell time (CDT)—and the human-based sensors, to a mobile application that lets the users be able to provide feedback on traffic congestion levels along with the automatically discovered vehicle position.

The major challenge that is crucial for the system to succeed is how to make the program be widely adopted. Thus, we have carefully studied user-centric needs by conducting a usability evaluation against five perspectives, i.e., efficiency, effectiveness, satisfaction, safety, and learnability. The results will be used as a guideline in developing the system in the future.

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J. Jaroenjanyakul, S. Phosaard, and W. Polnigongit are with the School of Information Technology, Institute of Social Technology, Suranaree University of Technology, 111 University Ave., Muang, Nakhon Ratchasima 30000, Thailand. (phone: +6644-224-273, e-mail: infotech@sut.ac.th, s@sut.ac.th, and weerap@sut.ac.th).

W. Pattara-Atikom is with the National Electronics and Computer Technology Center (NECTEC), under the National Science and Technology Development Agency (NSTDA), Ministry of Science and Technology, 112 Thailand Science Park, Phahon Yothin Rd., Klong 1, Klong Luang, Pathumthani 12120, Thailand (e-mail: wasan@nectec.or.th).

This paper is organized as follows: In Section II, we describe related works concerning traffic congestion report, and usability evaluation. Architecture of the proposed system is presented in Section III. In Section IV, we discuss the usability evaluation results. Section V provides results and discussion, and Section IV offers a conclusion and the possibilities of future work in this realm.

II. Related Works

Collecting traffic information using devices in the past was mainly an automatic system. There have been several works using the cellular phone systems to estimate vehicle volume [2], [3], travel times [4]–[8], traffic density, and vehicle velocity [4], [5], [8]–[10]. However, most of these works were based on simulations, mathematical models, or required additional equipments, such as a special antenna to collect traffic data. In contrast, our approach is based on an implementation of software running on mobile phones. In our previous work [11], we enhanced the use of the CDT, the time that a cell phone attaches to a particular phone base station, to estimate the degree of congestion, and this achieved a certain level of accuracy. The study in [12] considered traffic density and speed on highways, but our measurements reflected traffic conditions on signaled local roads. Moreover, we used CDT as a traffic congestion indicator which covered a larger area than the estimations in [2] and [3] that were based on received signal strength indicators (RSSI). In [2] and [4], traffic monitoring was performed only when the mobile terminals were in active mode (in a conversation), while our approach allowed the monitoring to be done in both active and idle modes (power on). Other studies that aimed to determine the levels of congestion from traffic flow information include [13], [14], and [15]. [13] estimated five traffic statuses from video images using hidden Markov models. [14] and [15] used fuzzy logic to determine continuous and six discrete levels of congestion, respectively. Both systems used velocity and vehicle volume as inputs into their fuzzy inference systems.

Besides the CDT, our system opens an opportunity to derive more exact vehicle movement information by allowing the user to be able to attach the GPS device which can generate the traffic reports according to [16] and [17].

Those research works were different from this system in that the user feedback system depends mainly on the opinions given by people. The users' opinions on congestion levels can be directly reported without computer congestion estimation. Thus the report is considered more sensible since congestion degrees may vary from one place to the others while the traffic flow remains the same due to several factors as stated. In addition, this user feedback system utilizes mobile network cell site information that can be captured on the mobile phone. There is no need to interfere with the phone service providers which sometimes are not willing to intrude on the customers' privacy.

To lay out the strategy for attracting as many users as possible, to obtain accurate and reliable information, and to provide a safe usage on the road, an intensive usability study is needed. The comprehensive review of the usability guidelines is elaborated in the following paragraphs.

A usability test is a part of usability engineering process which can be compared to the measure of the quality that the users experience when interacting with the user interface [18]. Many researchers have defined usability as shown in Table 1 such as (1) Shackel proposes to measure usability on 5 dimensions, which are effectiveness (speed), learnability (time to learn), learnability (retention), effectiveness and attitude. (2) Nielsen defines usability as consisting of 5 kinds of attributes, which are efficiency of use, learnability (ease of learning), memorability, errors/safety, and satisfaction. (3) ISO 9241-11(1998) defines usability as consisting of 2 kinds of attributes, which are efficiency and satisfaction (comfort and acceptability of use) [19]. We further explore usability focusing on mobile phone application and select a set of elements and assess to improve the system.

For mobile application usability, there has been research about usability testing for mobile phones, comparing between tests in the laboratory and in the field in order to find out whether they are different. They are differences [18]. Even though the test was done in the same laboratory, the results were different according to body motion [20]. User interface is also a factor affecting usability. Ketola and Röykkee divided user interface into the 7 following parts: Input, display, audio and voices, ergonomics, detachable parts, communication method, and applications [21]. Besides, the size of the screen [21], [22] and limitations of buttons [22] also affect usability. To fully assess all of the interfaces and functionality issues, we decided to explore all elements of the usability guidelines by compiling the similar items in into 4 elements in terms of efficiency, effectiveness, satisfaction and learnability. The detailed methodology is elaborated in the section IV. The tests were applied on the implemented traffic information feedback system presented and demonstrated in the next section.

TABLE I
Usability Attributes of Various Standards or Models [19]

Constantine & Lockwood (1999)	ISO 9241-11 (1998)	Schneiderman (1992)	Nielsen(1993)	Preece Et Al. (1994)	Shackel (1991)	User feedback system
Efficiency in use	Efficiency	Speed of performance	Efficiency of use	Throughput	Effectiveness (Speed)	Efficiency
Learnability		Time to learn	Learnability (Ease of learning)	Learnability (Ease of learning)	Learnability (Time to learn)	Effectiveness
Rememberability		Retention over time	Memorability		Learnability (Retention)	Satisfaction
Reliability in use		Rate of errors by users	Errors/safety	Throughput	Effectiveness (Errors)	Safety
User satisfaction	Satisfaction (Comfort and acceptability of use)	Subjective satisfaction	Satisfaction	Attitude	Attitude	Learnability

III. ARCHITECTURES

A. System Requirements

The system is used to allow the users to report the traffic congestion level without the burden of locating their position by themselves. There are two important requirements.

Firstly, the system should provide the user interface that is as simple as possible for the user to select the traffic congestion levels among: "flow", "heavy" and "jam," according to the traffic conditions on his/her current route. Secondly, the mobile unit must have the ability to identify its location automatically. User opinions on the traffic congestion and the corresponding locations will be sent to the road traffic information server. Without this automatic position discovery, the users have to browse for the listed locations or have to type in the street name by themselves, which is a major obstacle. We introduced the use of the CDT to roughly locate the vehicle position. GPS, which is more accurate to pinpoint the vehicle location, is also used in the supporting devices. Thus, the ability of the system to allow the user to select whether to use CDT, GPS or both, is an additional requirement.

The automatically generated traffic congestion report without the need of the users' opinion is also a byproduct of the system. By continuously and automatically feeding the vehicle location back to the server for particular intervals, the system can calculate roughly the traffic flow rate. This rate can be interpreted into congestion levels with the estimation algorithms. The user could set the device to routinely send out the locations.

The following section illustrates how the requirements above can be achieved.

B. System Components & Development Tools

The system was developed using Python programming language. Python programming provides efficient libraries to interface with the phone's operating system APIs to retrieve the real-time cellular network information. This system developed by Python can operate on Symbian, a widely-used mobile phone operating system.

The system utilizes General Packet Radio Service (GPRS) to transfer the user feedback and the location information from mobile phone to the server. This system was tested on the Nokia N72 phone, with a 2.1-inch display and the resolution of 176 x 208 pixels, operating on Symbian Series 60 version 2. Symbian is a popular operating system designed specifically for smart mobile devices. Our system can be widely adopted by a large number of mobile phone users since plenty of Symbian-compatible phones are in use (165 million Symbian phones were shipped since 1998 [23]).

The information regarding the location and movement of the vehicle sending back to the server could be obtained in the CDT or GPS mode. According to [24] concerning the mechanism of the CDT, a mobile phone service provider generally installs multiple base stations, and hence multiple cells, to provide city-wide coverage. A mobile phone registers itself to the nearest base station in order to make itself known to the network. CDT is the duration that the phone remains registered to a base station before changing the station. A high CDT value indicates that the phone remains within a cell for a long period of time. The system also collects the identification of the base station.

In the GPS mode, the data obtained from the satellites via GPS receiver is collected. The information derived and extracted are latitudes and longitudes which locate the position on the earth. GPS gives more accurate information than CDT but it requires an extra device. The GPS data could be used at the same time with the users' opinions, as in the CDT mode. The following section describes how all of the components explained above integrate and work.

C. System Flow

As demonstrated in Fig.1, the system gathers three essential pieces of information: user opinions, the CDT data and the GPS data. The user representing human in the diagram provides the opinion on traffic congestion degree by pressing the phone button 1, 2 or 3 representing the choices flow, heavy, and jam respectively. The CDT data, discovered in the low level of the mobile system, contains the time that the phone attaches to the service station along with its identity information. The GPS data contains latitudes and longitudes of the device receiving the information from the satellites.

The user opinions along with the CDT data, the GPS data, or both will be transmitted via GPRS reaching the web server, and then it stores the information into the database. The data is sent to the server when the user presses a button to provide feedback. The data is also automatically sent by a configured interval along with the user-triggered data.

D. User Interface

Besides the installation pages, the system provides the user two main screens, the configuration screen and the feedback screen, to keep it as simple as possible. When the user starts the program, they can give the opinion on the traffic congestion degree right away by pressing the phone button 1, 2 or 3. The system then acknowledges the feedback by displaying the provided congestion level along with the corresponding color bar. Color bars green, yellow, and red represent the congestion levels flow, heavy, and jam respectively. The user can choose between displaying the CDT data or the GPS data along with the feedback data. The captured screen in the center of Fig. 3 demonstrates the example screen with the feedback "Heavy" corresponding to the color bar shown in yellow. Fig. 2 gives examples of the CDT and GPS data configuration screens, for example, the interval of the automatically data feeding

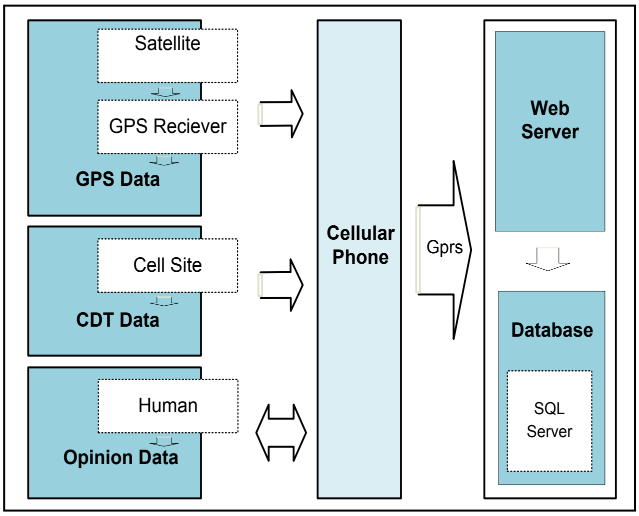

Figure 1: The Overall Architecture

IV. Usability Testing

A. *Subjects*

According to the usability evaluation guidelines, the number of usability testing subjects can be as few as 5 persons [25]. The system was tested with 30 users in the Bangkok metropolitan area, 5 of whom were randomly chosen for interviews. In order to gain the most reliable and accurate information on traffic condition in a short time, the test was done with the persons who frequently travel on the road, whether by private vehicle or public transportation system, and who always use a mobile phone.

B. *Tasks*

In the usability testing of the system, the users performed the following tasks: setting up the program, choosing between the CDT, the GPS data, or both, to locate the vehicle, and providing feedback regarding road traffic congestion degrees.

C. *Procedures*

In the first step, the users were given overall details about the program so that they would be familiar with the system. The users then tested every function according to the designed scenarios. Afterwards, the users completed the questionnaire to evaluate the usability of the system in terms of efficiency, effectiveness, satisfaction, learnability and safety by the questions designed for each element. The questions are 5-scale opinion rating questions. The scale ranges from 1 to 5, 1 being "strongly disagree" and 5 being "strongly agree" to the questions. The opinion rating ranges were weighted according to the standard of test assessment as follows:

TABLE II
Standard of Test Assessment

Standard Mark	Meaning
4.51 - 5.00	Strongly agree
3.51 - 4.50	Agree
2.51 - 3.50	Neutral
1.51 - 2.50	Disagree
1.00 - 1.50	Strongly disagree

During they experience the program, we observed the behaviors of users in terms of what they found easy and what were their difficulties. Afterwards, the users were be interviewed regarding their opinions and suggestions on using the system in every step.

V. Results and Discussions

Most of the 30 evaluators were undergraduate students aged between 19 and 25 years, and had 1-5 years of driving experience. They spent 1-2 hours each day in traffic. They used mobile phones every day. The usability testing results of the questionnaires are given and discussed along with the findings from the observations and the interviews according to five evaluation categories as follows:

A) *Evaluation on Efficiency*

Efficiency evaluation reflects mainly on the capability of the program's main functionalities. In order to evaluate the users' opinions towards the efficiency of the program, we outlined eleven usability investigation questions to cover the efficiency aspect as follows: 1) The program can be easily installed; 2) The CDT information reporting module is easy to activate; 3) The GPS information reporting module is easy to activate; 4) The colors indicating the congestion levels are meaningful; 5) The overall system is easy to use; 6) The speed in displaying the CDT data is appropriate; 7) The speed in displaying the GPS data is appropriate; 8) The time to wait for the acknowledgement from the server after giving the traffic opinion is appropriate; 9) The number of choices for the feedback (Flow, Heavy, and Jam) is enough; 10) The CDT information reporting module is easy to turn off; and, 11) The GPS information reporting module is easy to turn off.

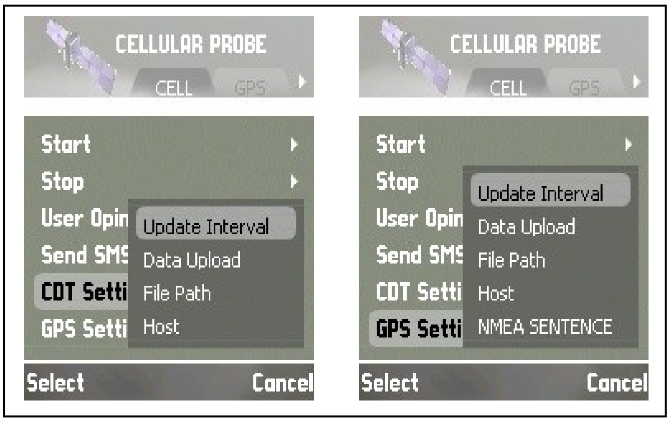

Figure 2: CDT/GPS Configuration Screen

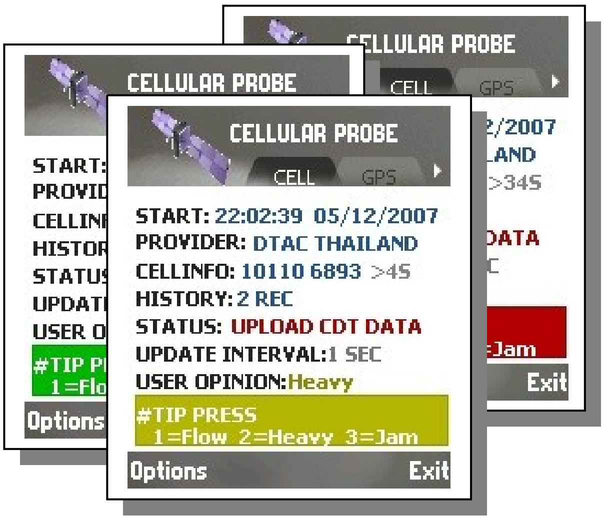

Figure 3: Main screens displaying CDT data and the congestion level reported

Fig. 4 exhibits the usability based on efficiency of the system's core functionalities. The results split into two groups. Roughly half of the evaluation matrix achieved the "agree" level, which revealed that the system performed well in general, and there is room for the system to be improved. Column number 4 shows the highest score of 3.97. This indicates not only that the road users were happy with using the color green, yellow and red for the congestion levels, but that the selected interviews revealed that this set of colors is a "must have" element of the system, as well. The slightly different scores of the items number 6 (3.80) and 7 (3.57) suggest that the speed of displaying GPS data should be improved.

Most of the ratings which lie in the neutral range relate to the system's ease of use. The installation and configuration process might need to be simplified to achieve higher efficiency scores according to the items

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number 1, 2 and 3. Item number 5 shows a score of 3.37, the lowest in this category, and this suggests that the overall user interface needs improvement. Several users were puzzled with the numerous cryptic abbreviations, text and numbers. The experiment suggests that this information, for example, “start,” “provider,” “cellinfo” and so on as demonstrated in Fig. 3, should be hidden from the general users. The score of item number 9 (3.37) suggests that the number of choices for the congestion level could be increased. The initial recommended number of levels is 5, which needs further study.

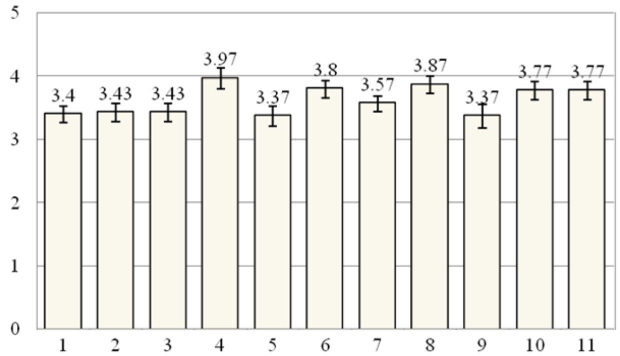

Figure 4: Evaluation ratings on Efficiency

B) Evaluation on Effectiveness

The effectiveness evaluation measured the successful rates of the activities performed by the users on key system’s functionalities. It is important in determining whether or not the system is ready for wide-distribution. The questions used to assess the effectiveness are: 1) The CDT information reporting module works as expected after the configuration; 2) The GPS information reporting module works as expected after the configuration; 3) The system successfully displays the feedback chosen by the user.

According to Fig. 5, the system is effective enough to be used in the real-world since the opinion ratings ranged from neutral to agree level. Sending feedback, which is the nucleus of the program, could be performed effectively according to item number 3. However, an easier setup process of the auxiliary technical components like the CDT and the GPS module should be provided. The users were confused because they did not know how the modules work and what the purposes of the processes were. Thus we could improve the process by trying to make it as automatic as possible and might provide a short clip to give an overall idea about the system.

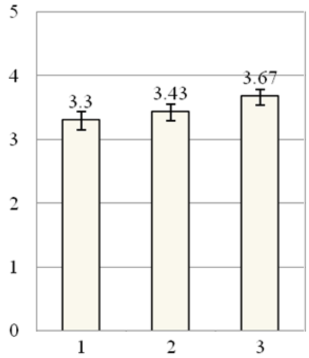

Figure 5: Evaluation ratings on Effectiveness

C) Evaluation on Satisfaction

The satisfaction of the users was measured mainly on the interface experiences. Attracting as many users as possible is one of the critical factors to accomplish the goal of the system. Five questions that were used to assess the users’ satisfactory were given as follow: 1) The program looks clean and neat; 2) You are satisfied with the overall system appearance; 3) The colors used on the screen are appropriate; 4) The graphics and images used on the screen are appropriate; 5) The font faces and the sizes of the text used on the screen are appropriate.

According to Fig. 6, the overall satisfaction of the users towards the program was in the “neutral” range. Although we expected the higher scores, the experiment suggested that the system should provide less information which the users do not need to know. The system needs more aesthetic attraction to draw more people to use the program. Fifty percent of the testers preferred more animations.

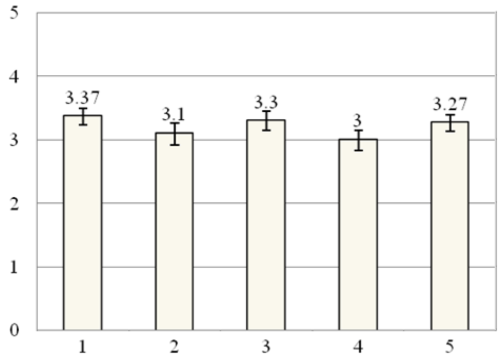

Figure 6: Evaluation ratings on Satisfaction

D) Evaluation on Learnability

The following questions assess the users’ learnability on using the traffic report system: 1) Words and sentences on the screen are easy to interpret; 2) The instruction guide is easy to understand and helpful; 3) You can learn how to use the system in a short period of time; 4) You can learn how to set up and configure the CDT information reporting module in a short period of time; 5) You can learn how to set up and configure the GPS information reporting module in a short period of time; 6) You understand the objective of the system.

The system still needs several improvements on the ease of use. From Fig. 7, almost all—5 out of 6—of the learnability items assessed scored in the “neutral” range. An introduction video clip and more user-friendly interface should be introduced in the next release.

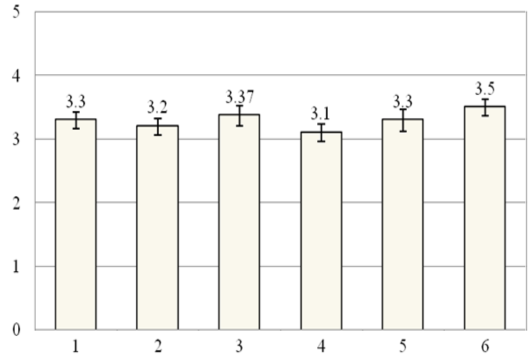

Figure 7: Mean ratings for Learnability

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E) Evaluation on Safety

Besides the regular usability testing, the safety is our major concern. The user rated that they could use the program efficiency while driving by 3.20 placing in the "neutral" range. However it was strongly recommended that users the system while the vehicle is in a complete stop. It is illegal in some countries to use mobile phones while driving. It was suggested that speech recognition may help deal with the problem of "talking and driving" if introduced to the system.

The average of all usability areas that we studied was 3.43, which is in the upper "average" or "neutral" level, which almost achieved the "high" or "agree" level.

Figure 8: Summation Results on the Usability Evaluations

According to the overall scores on usability evaluation as shown in Fig. 8, the system worked well in its core functionalities indicated by the scores of efficiency and effectiveness. The system should be enhanced in its attractiveness and its ease of use indicated by the lower scores of satisfaction and learnability.

VI. Conclusion and Future Work

Human-based traffic sensor application in mobile phones was introduced, and evaluated, in this paper. The human-based traffic sensor is novel in that it can provide traffic information in real-time, with high accuracy and wide coverage area, better than any traditional traffic sensors can, especially when a large number of volunteers participated. The ease of use (or usability) and incentives to attract volunteers are the keys to the success of the proposed human-based traffic sensor. In this paper, five usability factors (i.e., efficiency, effectiveness, satisfaction safety, and learnability) were thoroughly evaluated. The results are promising and reveal that all usability measures are perceived positively in the range of 3.10 to 3.97 on a scale of 5. This suggests that the proposed human-based traffic sensor can be a viable solution to complement existing and yet limited traffic sensors in Thailand. The integrity of the users' opinions is a subject to further investigate.

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