DEVELOPMENT OF A SMART PHONE APP "SAFETY SUPPORTER" FOR ASSISTING DRIVER'S SAFE DRIVING[1]

Junyi ZHANG
Professor; Graduate School for International Development and Cooperation, Hiroshima University, 1-5-1 Kagamiyama, Higashi Hiroshima, 739-8529, Japan;
+81-824246919; zjy@hiroshima-u.ac.jp
Ying JIANG
Doctoral Candidate; Same affiliation as the first author; jiangying119@msn.com
Katsushi SASAKI
Master Candidate; Same affiliation as the first author; m134975@hiroshima-u.ac.jp
Masaki TSUBOUCHI
Manager; Traffic Engineering and Planning Division, Chugoku Branch, West Nippon Expressway Co., Ltd., 2-26-1, Midorii, Asaminami-ku, Hiroshima, 731-0103, Japan;
+81-828311914; m.tsubouchi.aa@w-nexco.co.jp
Takeshi MATSUSHITA
Assistant Manager; Same affiliation as the fourth author; t.matsushita.ab@w-nexco.co.jp
Toru KAWAI
Manager of Information Division; VitalLEAD Co Ltd., Japan; kawai_t@vitallead.co.jp
Akimasa FUJIWARA
Professor; Same affiliation as the first author; afujiw@hiroshima-u.ac.jp

ABSTRACT

Traffic accidents are mainly caused by human errors and it therefore becomes important to explore what kinds of individualized traffic safety measures are more effective to prevent the occurrence of accidents. In line with such consideration, a GPS-enabled smart phone App “Safety Supporter” was developed to diagnose the driving safety based on both objective and subjective indicators. Objective indicators look at the compliance level of speed limit, acceleration and deceleration, and smoothness of driving in a given time period only based on GPS information. Subjective indicators include a self-diagnosis of actual driving safety after each drive and a set of self-reported driving propensity. Furthermore, the App provides drivers with traffic warning information. The applicability of the App was confirmed by implementing a social experiment, where about 100 drivers were asked to actually use the App for three months. During the experiment, different diagnosis and information provision scenarios were tested and a series of questionnaire surveys covering driving behavior and behavioral change as well as their influential factors was conducted with respect to each scenario. Finally, some issues for the future deployment of such individualized traffic safety measures are identified and the possibility of applying the App to serve as an alternative data collection tool for traffic incident management is discussed.

Keywords: Individualized diagnosis of driving safety, smart phone App, warning information, accident blackspot, driving fatigue, self-diagnosis, expressways, incident management, Japan

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1. INTRODUCTION

Traffic accidents are mainly caused by human errors (e.g., Parker et al., 1995; Verschuur and Hurts, 2008), which may differ across divers. A driver may cause different types of accidents due to the same error. Different errors may lead to the same type of accidents. These suggests the existence of heterogeneity in the causes and outcomes of traffic accidents and consequently the necessity of taking individualized traffic safety measures (by reflecting each driver's specific characteristics). Therefore, it becomes important to explore what kinds of individualized measures to prevent the occurrence of accidents are more effective. Especially, it has been a considerably difficult challenge how to effectively implement these measures, considering temporally decaying effects of the measures and drivers' willingness to accept and follow the measures.

Individualized traffic accidents prevention measures have been taken in a limited way. For example, in Japan, traffic safety education starts from elementary schools, meaning that almost all Japanese people have been educated. Drivers are also required to update their driving licenses regularly (every 3 – 5 years, depending on the type of driving license and experience of causing traffic accidents), where traffic safety training (video-based and guidance by instructors) is provided with general information about traffic accidents and safety measures with respect to an arbitrary group of drivers for about 30 – 120 minutes each time. However, the effects of such undifferentiated education on the prevention of traffic accidents are questionable. Community-based traffic safety education initiated by local police agencies and/or local residents is popular, especially for children, young people and elderly people, but the problems are that participants are limited and really risky drivers do not participate, as expected. Traffic safety campaigns have been deployed in spring and fall every year with respect to the general public, not each individual driver. As for road-related traffic safety measures, road-side and on-road traffic signs and variable message signs shown on road-side electronic boards are dominating, but once drivers become familiar with them, the effects of preventing the occurrence of traffic accidents decay. Again, these measures are provided to the general public, not each individual driver. Effects of all the above measures may be further worsened by the fact that drivers' safety consciousness may change as time passes due to a variety of reasons from both internal and external environments.

Stradling (2011) identified the following ten driving tasks relating to driving safety. Each task corresponds to a different part of the 300-29-1 ratios (1 serious accident occurs, behind which 29 minor accidents and 300 risky actions take place) suggested in the famous Heinrich's Law.

(1) Strategic tasks: decisions on activity choice, travel mode and departure time choice, and recognition of route alternatives and travel time.
(2) Navigation tasks: find and follow chosen or changed route, identify and use landmarks and other cues.
(3) Road tasks: choose and keep correct position on road.
(4) Traffic tasks: maintain mobility while avoiding collisions.
(5) Rule tasks: obey rules, regulations, signs, and signals.
(6) Handling tasks: use in-car controls correctly and appropriately.
(7) Secondary tasks: multitasking during driving.
(8) Speed tasks: maintain a speed appropriate to the condition.
(9) Mood management tasks: avoid boredom and anxiety.
(10) Capability maintenance tasks: avoid compromising driver capability with alcohol or drugs, fatigue, or distraction.

All the above statements suggest that efforts made by each individual driver are more important than other measures. One can see that what public sectors, firms, and communities and so on can assist drivers to improve their driving safety is limited. Policy makers should shift their policies directed toward individual drivers, rather than general drivers. It is essential how to reflect individual drivers' heterogeneity into traffic safety policy decisions from both outcomes and causes.

Individualized traffic safety measures need individualized tools. Mobile phones may become one of such tools considering their rapid diffusion in many countries, which may improve driver's risk recognition, judgment, and operation. Applications of mobile phones in transportation are becoming more and more popular, mainly in providing trip makers with previously unavailable information (e.g., Bonsall, 2000；Herrera et al., 2010). Policy makers are interested in using them to collect information for traffic control and management as well as road maintenance, e.g., travel time measurement and prediction, measurement of road roughness for maintenance. Especially, it is worth exploring the ability of smart phones. Smart phones do not have just telephone functions. They have been developed just like a mini note PC, where various PC functions, music and video play functions are contained. Especially, a variety of application software (simply called App) can be easily downloaded via the Internet. With these Apps, various convenient services become accessible. Because of such attractiveness, the number of smart phone users has been rapidly increasing year by year. As stated by Brazil and Caulfield (2013), the rise of smart phone applications within the transport sector has created new and exciting opportunities to provide users with a wide range of previously unavailable information services, and while these applications are becoming more readily available in the market place, little in terms of scientific research has been undertaken to examine their influence on users.

Motivated by the above-mentioned matters, the objective of this study is to develop a GPS-enabled smart phone App (called *Safety Supporter*: [2]) that diagnoses driving safety by making full use of GPS information and provides advices and traffic warning information to drivers for the prevention of traffic accidents. We also conducted a pilot field survey.

In the remaining part of this paper, first, we briefly introduce existing GPS-enabled smart phone Apps with functions of driving safety diagnosis. Second, we describe how to implement the diagnosis of driving safety in the *Safety Supporter*. Third, we explain the development of the *Safety Supporter*. Fourth, we provide a preliminary analysis of the pilot field experiment. Finally, we conclude this study.

2. EXISTING DIAGNOSIS APPS OF DRICING SAFETY

Since 2013, five insurance companies in Japan have started services of diagnosing driving safety based on their developed smart phone Apps. All these Apps were developed under the iOS and Android environment and can be downloaded for free. Details are shown in Table 1.

Major shortcomings of these existing safety diagnosis tools are shown below.

(1) The measurement mainly focuses on driving skills, but not directly on driving safety.
(2) The scoring of safety level is arbitrary and does not reflect actual safety level. To avoid any worse influence of excessive confidence for driving, developers purposely lowered

[2] It can be downloaded for free from Google Play (Japanese site), named セーフティサポーター.

the safety level (NEXCO RI, 2013). The purpose of the development is understandable; however, that may lead to unrealistic diagnosis, which may hinder the active use of the Apps.

(3) The Apps do not reflect road-specific features related to traffic accidents. Some road attributes tend to increase the possibility of traffic accidents, which should be properly informed to drivers.

(4) There are no Apps developed for expressways. Once an accident occurs on an expressway, it is much more likely to result in a serious accident than on an ordinary road. Therefore, special attentions should be paid to the development of relevant Apps for expressways.

Table 1. Smart Phone Apps with Diagnosis Functions of Driving Safety in Japan

Company	Name of App	Main functions
Sony Assurance Inc.	Japanese name: ﾄﾞﾗｲﾊﾞｰｽﾞﾅﾋﾞ (DriversNAVI)	・Scoring for brake, stop, steering, right turn and left turn, and smoothness (full points: 20 for each; in total, 100) ・Trajectories of driving routes and speeds ・Driving recorder ・Fuel efficiency display ・Maintenance information
Sompo Japan Insurance Inc. Nipponkoa Insurance Co., Ltd.	Japanese name: ｾｰﾌﾃｨｻｲﾄ (Safety Sight)	・Scoring for inter-vehicle distance, steering, accelerator, brake, and continuous driving (full points: five stars for each) ・Trajectories of driving routes and speeds ・Driving recorder ・Alarm of collision to the vehicle ahead ・Contact information in case of emergence
Mitsui Sumitomo Insurance Co., Ltd.	Japanese name: ｽﾏ保 (SumaHo)	・Scoring for stability of acceleration, stability of deceleration, stability of cornering, stability of steering, and eco-driving (full points: 20 for each; in total, 100) ・Driving propensity based on back-forth, right-left and up-down jolting ・Driving recorder ・Driving suitability test ・Navigation under emergent troubles
Aioi Nissay Dowa Insurance Co., Ltd.	Japanese name: ｻﾎﾟ NAVI (SaPoNAVI)	・Scoring for brake, stop, steering, right turn and left turn, and smoothness (full points: 20 for each; in total, 100) ・Cognition of driving dangerousness by showing videos of actual driving ・Hazard map of traffic accidents ・Alarm of snoozing ・Guidance of responses to emergent situations

Source: Revised based on NEXCO RI (2013) and the websites of the above companies

3. DIAGNOSIS OF DRIVING SAFETY

Traffic accidents occur with driving speed changes. If all vehicles were driven at the same speed, traffic accidents would not occur. If a driver does not drive under the speed limit, the probability of causing accidents may increase, as known by the fact that over-speeding is one of major causes of traffic accidents. If the driver makes a sudden stop or start, or does not drive smoothly, he/she may cause an accident with a higher probability. In line with such considerations, observing changes in driving speed and informing drivers about the consequences of the changes may provide useful insights into the prevention of traffic accidents. Accordingly, we propose diagnosing the driving safety level from the following three perspectives: i.e., *compliance level of speed limit*, *instantaneous change of speed*, and *smoothness of driving*. We show details below. Vehicle locations can be captured every second. Considering the data processing speed and the capacity of data saving server, diagnoses are implemented every two seconds.

3.1 Compliance Level of Speed Limit

Speed limit is set for safer driving. Obeying speed limit more likely results in safer driving and violating speed limit is more likely linked with the occurrence of an accident. In other words, the higher the over-speed the more dangerous. Therefore, here, the degree of over-speed can be used to measure the driving safety level. Here, we treat every two seconds as a sample and score the driving safety level. Concretely speaking, the safest level is given 100 points when driving speed is equal to or slower than speed limit plus 5 km/h (5 km/h is set considering the errors that a driver judge the speed) and the most dangerous level is given 0 point when driving speed exceeds speed limit for more than 50 km/h. Other driving speeds are scored depending on how much speed limit is violated. The scoring is measured by reflecting the fine levels determined by policy agencies in Japan.

3.2 Instantaneous Speed Change

If the absolute value of acceleration/deceleration is larger than 0.3 G or 2.94 m/s^2, the safety level is judged to be the most dangerous level, i.e., the score is equal to 0. If the absolute value is 0.0 G, the score of safety level is 100 points, i.e., the safest level. Other instantaneous speed changes are scored depending on how large of the acceleration/deceleration.

3.3 The Smoothness of Driving

The larger the variation of driving speeds in a traffic flow, the more dangerous the driving in the flow. To measure the dangerousness of driving from such a perspective, we define a time period that covers four seconds before and after a second under study, and the second, i.e., the total time period is nine seconds. If the driving speed is 80 km/h, the nine seconds correspond to the distance of 200 m. If the driving speed at a second within the nine seconds is equal to the median (Y) of all the nine speed values, the score of safety level is set to 100 points, i.e., the safest level. If the driving speed is beyond the range of $Y \pm 2\sigma$, where σ is the standard deviation, then the score of safety level is set to 0, i.e., the most dangerous level. Other speed values are scored between 0 and 100 points depending the deviation from the median.

3.4 Diagnosis of Driving Propensity

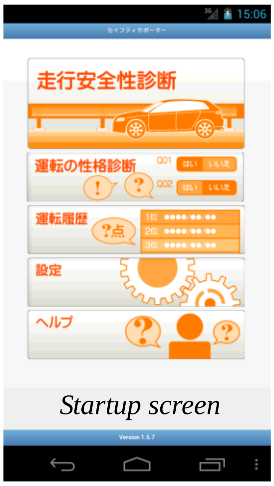
Different drivers may have different driving propensities and consequently respond differently to traffic measures. Driving propensity indicates a peculiar latent attitude or a kind of habit that are inherent to drivers. According to Japan Traffic Safety Association (2006), driving propensities can be classified into 6 types based on 27 question items as follows:

(1) Irritable driving: Drivers tend to be annoyed with other vehicles or pedestrians and drive with high stress. It is the case if four or more out of eight items targeted are selected.
(2) Careless driving: Drivers tend to frequently encounter dangerous driving experience during driving. It refers to the case that three or more out of nine items are selected.
(3) Aggressive driving: Drivers tend to make unnecessary lane changes during driving. If one or more out of three items targeted are selected, the driving is judged to be aggressive.
(4) Excessively-confident driving: Drivers tend to drive with excessive self-confidence. If none of targeted seven items are selected, the driving is judged to excessively confident.
(5) Indecisive driving: Drivers tend to drive with hesitation and insufficient confidence. If

four or more out of the target items in the above (4) are fitted, the driving is indecisive.

(6) Safe driving nature: Drivers tend to drive calmly in a balanced way. None of the above types are identified.

The above 27 items are used to measure different types of driving propensities. However, it is not difficult to imagine that different respondents might respond to several item categories simultaneously in a different way, and as a result, it might become difficult to clearly distinguish a certain type of driving propensity from other types. In reality, drivers' driving propensities might differ across driving situations. In other words, a driver might belong to two or more types of driving propensities simultaneously. We score the driving propensity based on how many types that a driver is classified into. If a driver is classified into the type (6), the score for driving propensity is set to 100 points. If a driver is classified into four or more types, the score is set to be 0, meaning that he/she is the most dangerous driver potentially. The scorings for other numbers of the propensity types are given between 0 and 100 points.



Startup screen

4. THE DEVELOPMENT OF *SAFETY SUPPORTER*

We developed a GPS-enabled smart phone App, called *Safety Supporter*, under the Android environment, which can not only diagnose the driving safety level, but also provide advices to drivers about the improvement of driving safety as well as traffic warning information on expressways. To our knowledge, this is first Apps with such warning information, especially on expressways, in practice.

Safety Supporter
Google Play

4.1 Functional Components of "Safety Supporter"

Safety diagnosis

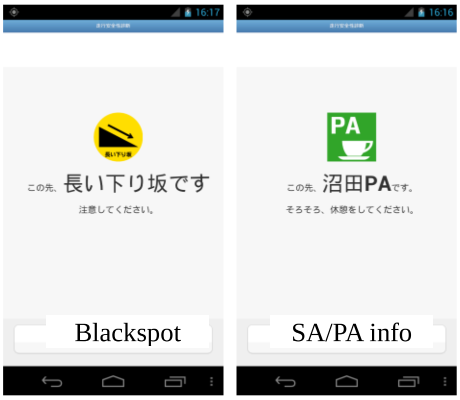
1) Objective diagnosis (the right two images)
   It is given with respect to compliance level of speed limit, instantaneous change of speed, and smoothness of driving. For each of the three diagnosis indicators, the diagnosis result is explained and advices about how to improve the safety level are provided.

Objective Diagnosis

2) Subjective diagnosis (the lower-right two images)
   (1) Diagnosis of driving propensity: Based on the self-reported evaluation, each driver will be classified into one of the previous six types. Depending on the types, *Safety Supporter* provides advices about how to improve the safety level are provided.

Diagnosis of driving propensity

(2) Self-diagnosis of driving: Before sending a request to the App *Safety Supporter* for the diagnosis, the driver can choose to diagnose the driving safety level by him/herself. This function is prepared for allowing drivers to understand the perception gap between their subjective evaluation and objective diagnosis.



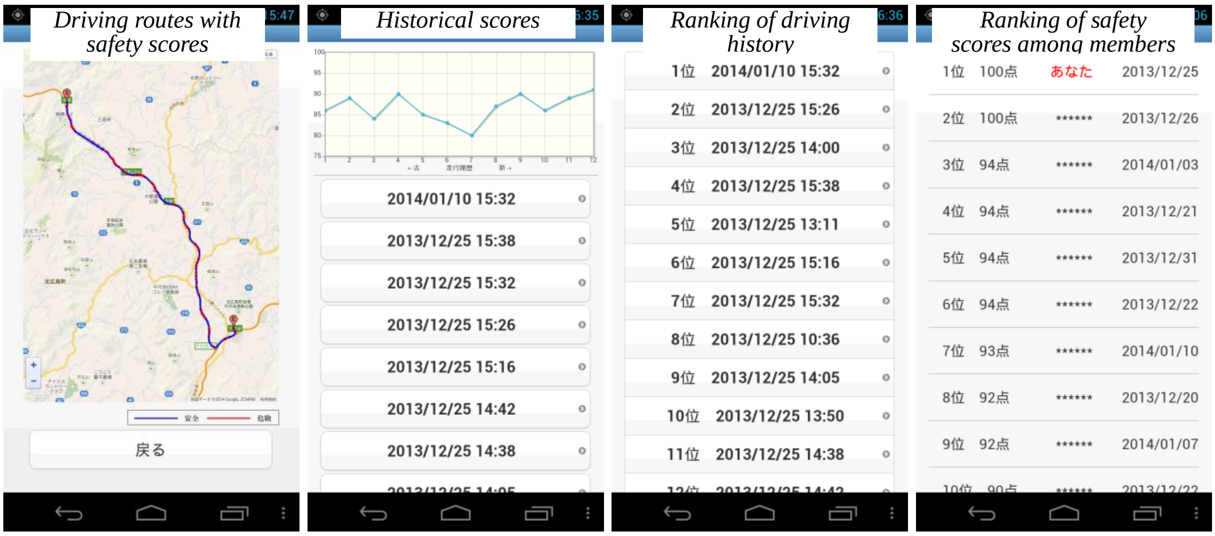
Information provision

Two types of warning information is provided only on expressways.

1) Black spots, i.e., dangerous road section, where traffic accidents occurred frequently
   Driving safety diagnosis and information provision when passing through black spots
2) SA/PA: Warning of fatigue for long-distance driving and automatic guidance of SA/PA.

Information feedback to drivers

1) Scores of driving safety
   Each time, a driver can choose to first make a self-diagnosis about their actual driving safety level and then he/she will be provided with an average score of the total measurement over the whole driving course and scores of compliance level of speed limit, instantaneous change of speed, and smoothness of driving. Drivers can skip the self-diagnosis step.
2) Trajectory of driving route with driving safety level
   Each time, after providing drivers with scores of safety level, a driver will be provided with a trajectory of driving route, where the driving safety level at each moment is shown in the map. In addition, the average score in the previous time is also shown. The App also stores all the measurement results so that drivers can review their previous driving performance.
3) Ranking over time among registered members
   As a social agency, drivers tend to compare with other drivers. The App prepares a function that show each driver's ranking among registered members.



4.2 System Design Considerations of *Safety Supporter*

For the current version of *Safety Supporter*, it is developed under the Android environment. It is also possible to develop under the iOS environment. Because we need to revise the App though a field experiment by reflecting the opinions and requests from drivers, to avoid any delay for the improvement of the App due to the approval time, we just developed the App within the Android system. Especially, for the iOS Apps, they must be a completed version for obtaining the approval. The program codes are made using the javascrip language under the smart phone development framework "Phonegap". The merit of using the Phonegap is that the program coded for the Android system can be directly applied to the iOS system.

Diagnosis by *Safety Supporter* can start at any time over the whole driving course. Both ordinary roads and expressways are targeted. However, only traffic warning information related to expressways is provided.

Basic information processing during driving
During driving, the longitude and latitude information is captured every second via GPS in order to identify the vehicle location. If the accuracy of GPD is extremely bad (e.g., when a vehicle is running into a tunnel), the App will not obtain the location information. Once the location is identified, the App searches for the relevant information within the 100 m radium and process the information, which includes dangerous road sections, IC, and SA/PA.

Privacy Protection
Measurements start after a certain length of time passes from the departure site and ends before arriving to destination.

Information processing after passing through the IC
In case of the measurement for expressway, it starts when the entry IC is approached and ends when the exit IC is approached. For avoiding wrong detections, IC points are pre-specified.

Information processing of dangerous road sections
If a dangerous road section, where traffic accidents have often occurred, is detected within a certain distance (can be defined by users; default: 2 km) from the current location of vehicle, the warning information will be announced. For each dangerous road section, the information of location, type of frequent traffic accident, road name, kilo-post, and down-stream and up-stream of road is stored.

Information processing of SA/PA
After a certain length of time (can be defined by users; default: 120 minutes) passes after the start of driving, the App will search for whether there is an SA/PA within the defined distance from the vehicle location. When the SA/PA is detected, it will be displayed.

Termination of measurement
Users can stop the measurement at any point in time. Formally, the App terminates the measurement once users push the button of "end of measurement". After that, users will be asked whether to send measurement results to the Web server of the App. Once the sending is done, the App will display the diagnosis results with scoring and driving trajectories on map.

Data accumulation
Information measured is stored in a Web server. To send the information to the server, user's

agreement is first required. In other words, only the information with users' agreement will be saved in the server.

Setting of User-specific values

Users can change values related to the provision of traffic information, which includes black spots and SA/PA.

- Driving time: the default value is 120 minutes.
  This value is used to diagnose driving fatigue. After the designated time passes, the APP will provide drivers with SA/PA information for taking a rest.
- Timing of information provision relating to black spots: the default value is 2 km to the current location of vehicle.

Usability considerations

Design and interfaces of *Safety Supporter* are developed by attaching the most importance to the safety during driving. Concretely speaking, (1) to start the measurement, only few touches are needed; (2) for the information of black spots and SA/PA, it is displayed with an icon and voice-based warning that driver do not need to watch the screen; and (3) users can use it without special setting.

5. PILOT FIELD EXPERIMENT

We conducted the pilot field experiment in the middle of December 2013 by inviting five university student drivers. We asked each driver to drive on five routes of expressways (Figure 1: pink, red, green, blue, and light blue routes), which are under the administration of the Chogoku Regional Branch, West Nippon Expressway Co. Ltd. (West NEXCO), Japan.

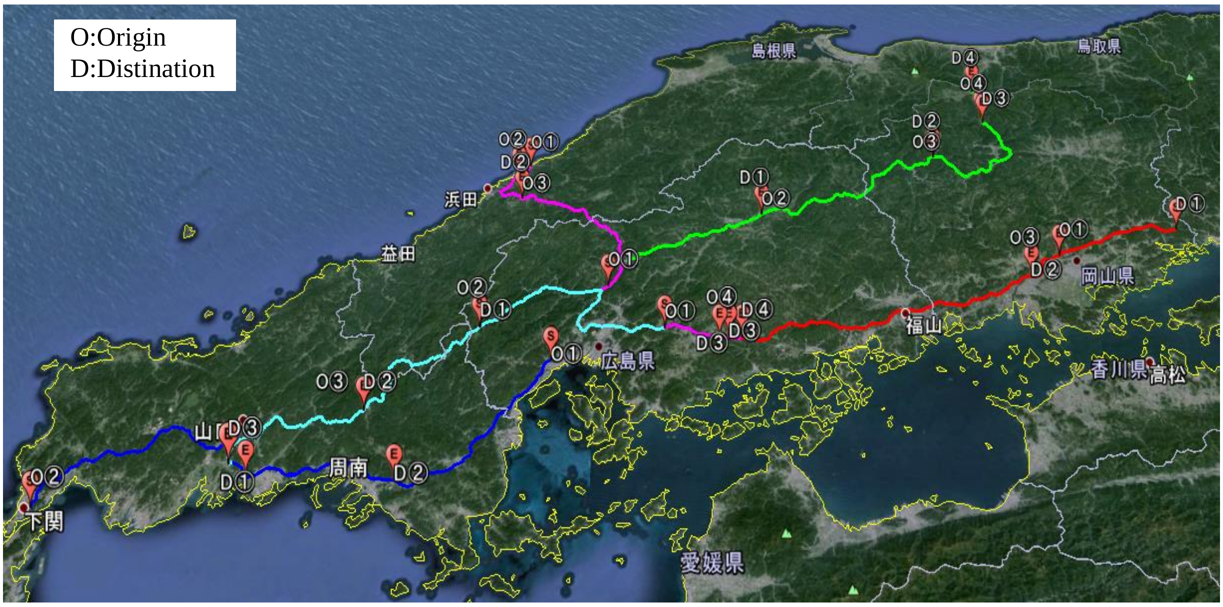


Figure 1. Driving routes.

We further show scores of all the three diagnosis indicators on the five routes in Figures 2-6. As for the over-speeding indicator, most of the scores were larger than 80 points. Because this was an experiment, it seems that student drivers tend to obey the speed limit. In contrast, the scores for acceleration and deceleration and driving smoothness show a considerably different trend. There are many moments when the scores were lower than 60 points. Especially, even under such an experimental situation, there were not few moments when scores were lower even than 10 points, suggesting that daily traffic flows on expressways may involve more risky driving actions. Such risky actions could be properly captured using the App developed.

We further calculated the correlations between the three indicators and found that these indicators did not perform consistently and their correlations (r11, r12, r13: (1) over-speeding, (2) acceleration and deceleration, (3) driving smoothness) just ranged between 0.02 and 0.19. These results suggest that all of the three indicators are needed to measure the driving safety level because they reflect different aspects of driving safety. Existing measurements of driving risks rely on the occurrence of actual accidents, which occur at specific road sections and specific time points. On the other hand, accidents can occur at any place and at any time. Accidents occur within seconds. Such second-based measurement is useful to capture driving risk in a continuous way.

6. EXPECTED OUTCOMES

First, it is expected that providing individualized diagnosis of driving safety and individualized advices for each driver could effectively assist the driver to improve their ability of preventing the occurrence of traffic accidents. The following changes can be expected and should be clarified during the full-scale field experiment, which is scheduled to be implemented from February 2014 and terminated in April 2014 by inviting 100 drivers.

(1) Awareness of drivers' own dangerous driving propensity might be enhanced. Change in the awareness might assist drivers to move from a dangerous stage to a safer stage over the whole process of behavioral change.

(2) The gap between objective safety level and subjective perception level might be shorten. This may be useful to drivers to take proactive measures to voluntarily enhance their driving safety level.

(3) Changes in driving tasks: In the Introduction, 10 driving tasks are identified. These tasks might be modified once drivers are provided with such diagnosis-based information.

(4) Self-improvement by social influence and the reference to driving experience: The ranking of driving safety scores is given with respect to all registered members to the App. Drivers are also provided with the diagnosis history, which might assist drivers to take a safer driving action by referring to the past driving experience. Such social influence and the reference to the driving experience are expected to positively contribute to the improvement of driver's driving safety level.

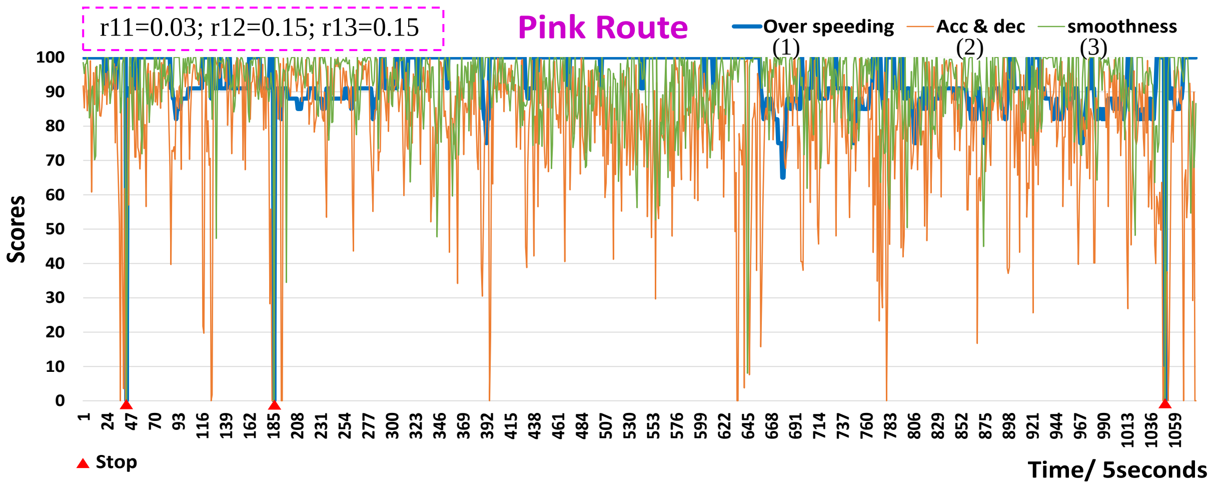


Figure 2. Scores of driving safety diagnosis on the pink route

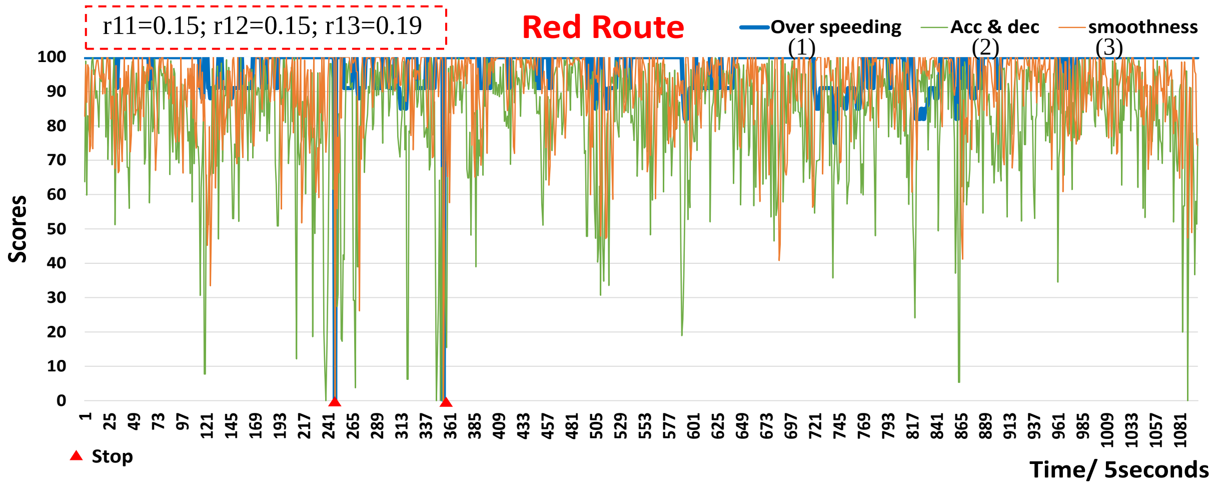


Figure 3. Scores of driving safety diagnosis on the red route

Second, the collected speed-related information from all registered members to the App system can replace some parts of existing traffic information collection functions. Especially, traffic accidents may occur at any point of road and at any time point. Unfortunately, existing traffic information collection systems mainly rely on point-based collection. However, in case of incident management, continuous monitoring of all road sections is required, which can be only realized by personally owned mobile devices (cell phones, tablet, etc.). Needless to say, such individualized information collections should be based on users' agreement. Herrera et al. (2010) revealed that a 2–3% penetration of cell phones in the driver population is enough to provide accurate measurements of the velocity of the traffic flow. It may be expected that a lower penetration of the App might be sufficient to capture the driving safety level for the whole traffic flow. Third, once the probe-based information becomes available, it can be used to better measure the driving safety level, where the current measurement cannot take into account the existence of other vehicles in the traffic flow. Last but not the least, diagnosis results from each driver can be gathered to identify risky spots on roads, which might be more useful to prevent traffic accidents than the information about historical accidents.

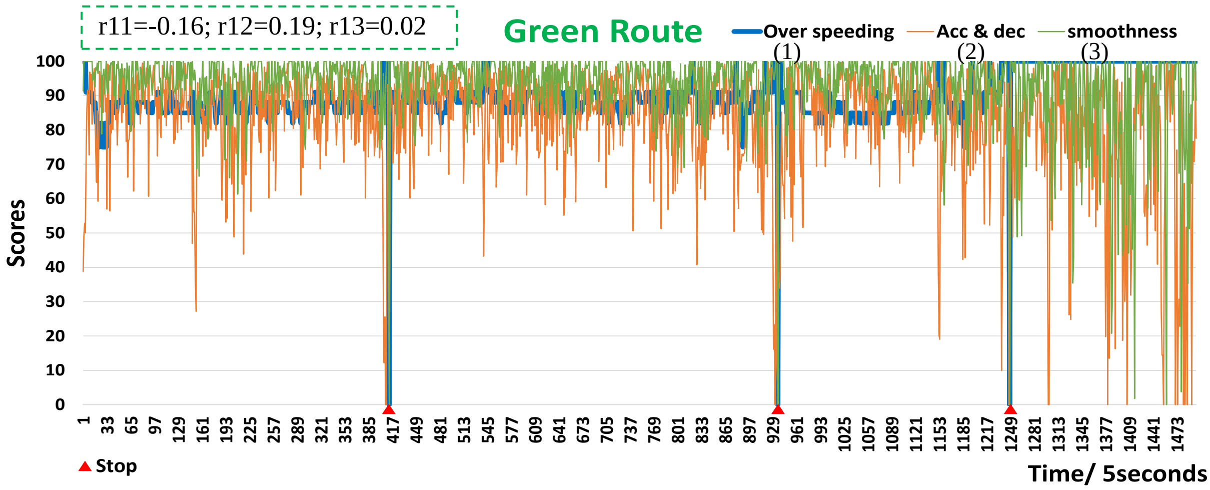


Figure 4. Scores of driving safety diagnosis on the green route

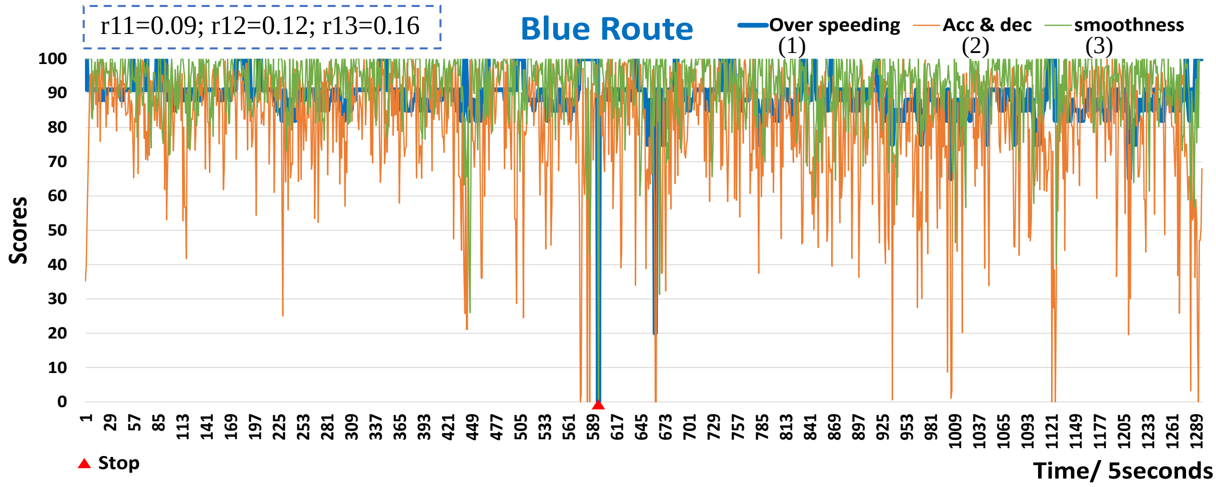


Figure 5. Scores of driving safety diagnosis on the blue route

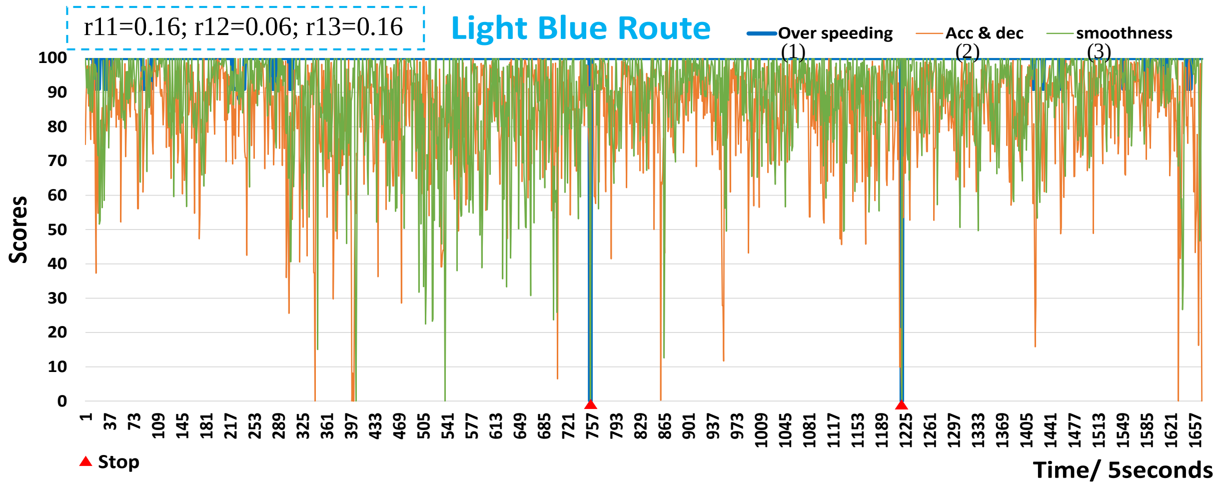


Figure 6. Scores of driving safety diagnosis on the light blue route

7. CONCLUSION

Motivated by the popularity and attractive functions of smart phones and the necessity of taking individualized traffic safety measures in practice, we developed a simplified driving safety diagnosis tool, which is a smart phone App (called *Safety Supporter*), by making full use of GPS information. As for objective driving safety, we measured and scored the compliance level of speed limit, acceleration and deceleration, and smoothness of driving in a given time period. We further scored drivers' self-diagnosis of actual driving safety after each drive and self-reported driving propensity. Especially, the App informs drivers on expressways before approaching an accident blackspot that is pre-specified, i.e., the information is static. It also warns and guides drivers to take a rest at SA/PA after driving for a certain length of time for mitigating the influence of driving fatigue on the safety, i.e., this information is dynamic. To attract more use of the App in future, the App does not record the measurement results nearby origins and destinations for privacy protection. The App is accessible for free in Japan. The App can be used not only to measure the driving safety and provide traffic warning information, but also serve as an alternative data collection tool for traffic incident management based on the "give-take" relationship between users and providers. We confirmed the applicability of the App by implementing a pilot field experiment. To actually deploy the App in the market, a full-scale field experiment is required. We already prepared for it. The App should be further improved by reflecting drivers' heterogeneous needs and the progress of information and communication technological development.

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