Usability Evaluation of Applying Quality Control Charts in In-Vehicle Forward Collision Warning Interface Design

Yung-Ching Liu, and Ching-Heng Ho

***Abstract*—**Forward collision warning (FCW) system is effective to help maintain appropriate headway between a host vehicle and the lead vehicle. In addition, control charts are well suited for adoption in car-following behavior evaluations. We conducted a simulator experiment to investigate 48 high and 48 low driving anger drivers' driving performances, and divided attention (DA) response tasks under both simple and complex driving conditions when FCWs are presented by five-stage, X-bar control charts or X-bar and exponentially weighted moving-average (EWMA) chart interfaces. The results show that high-anger drivers drive maintain shorter time to collision and headway than low-anger drivers, and FCWs provided a substantial benefit, particularly FCWs using X-bar control chart. The user experiences of FCWs improved the response time of braking, decreased the maximum longitudinal deceleration, and expanded the minimum TTC and headway with the lead vehicle, particularly the user experiences of FCWs using X-bar control chart.

***Keywords*—**forward collision warning, quality control chart, driving simulator, driving anger

I. Introduction

REAR-END collisions are the most common type of vehicle-related accidents. In Taiwan, the number of vehicles and density of road traffic have gradually increased in the past 20 years. Statistics show that 71 per 1,000 residents in Taiwan had at least one vehicle in 1985. In comparison, 293 per 1,000 residents in Taiwan had at least one vehicle in 2010 [1]. As the number of vehicles increased, road traffic became more disordered. Statistics from the Ministry of the Interior in Taiwan indicate that 199,903 traffic injuries or fatalities resulted from accidents on the road in 2010, and that traffic injuries in 2010 increased 8.2% from 2009 [2].

Drivers do not maintain safety time headway resulting from aggressive driving, negative driving conditions (i.e., fatigue and drunk driving), distractions, and inattention; therefore, unsafe time headway probably accompanies traffic collisions. Furthermore, driving anger is considered an emotion that is composed of anger-related feelings and thoughts provoked by traffic situations when driving. Numerous studies have demonstrated that driving anger is associated with aggressive driving behaviors and leads to reckless driving actions, such as speeding, excessive lane changing, tailgating, and improper passing [3]–[10].

Technological advancements have led to different vehicle manufacturers taking an interest in the development of forward collision warning (FCW) systems. Dingus et al. [11] used three on-road experiments to determine how headway maintenance and FCW displays influence driver behavior, and indicated that when drivers were provided with salient visual warnings presented by well-designed FCW displays, drivers effectively increased their time headway between their vehicle and the lead vehicle. In addition, auditory warnings were less effective than visual warnings for maintaining a safe headway, but were helpful for decreasing reaction time for deceleration. Maltz and Shinar [12] stated that distracted drivers increased their temporal headway with the lead vehicle by using a less reliable collision avoidance warning system, and by contrast, maintained shorter headways with warning systems having higher reliability levels.

Ben-Yaacov et al. [13] used auditory warnings to alert drivers that the temporal headway between the host vehicle and lead vehicle was too short, and indicated that drivers often overestimated their temporal headways to lead vehicles, a behavior leading to dangerous traffic conditions. In-vehicle collision avoidance warning systems have been proven to effectively aid maintaining an appropriate headway and reducing the risk of rear-end crashes. The majority of previously conducted studies have shown the benefits of FCW systems in reducing the number and severity of rear-end collisions [14]–[17]. However, they rarely considered individual differences in car-following behaviors. The safety distance of headway for each driver is different. Jamson et al. [18] proposed an adaptive FCW system that adjusted the timing of warnings according to each driver's reaction time. Although this did not cause significant differences in the adaptive and non-adaptive systems for non-aggressive drivers, the benefits of the adaptive system were demonstrated for aggressive drivers. Aggressive drivers reported a preference for the adaptive system and rated it as less "stress-inducing" and more "safety-enhancing" compared to the non-adaptive system. Therefore, we also intend to develop an adaptive FCW system by using the control chart concept and intend to determine the benefits of an adaptive

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system.

SQC tools are used to evaluate process capabilities and are applied broadly in the manufacturing industry. The traditional SQC tool to examine process performance is the Shewhart quality control chart. The control chart is a graph that is used to study how a process changes over a monitored duration. Shewhart control charts have been shown to be effective for identifying monitored process shifts as small as 1.5 SD [19], and are applied and developed properly for continuous data (i.e., time headway to lead vehicle). An EWMA control chart is an alternative to the Shewhart control chart, and has usually been more effective for detecting slight process shifts [19]. Per user requirements, two parameters, the weight factor (λ) and the multiple of the rational subgroup SD (L), are selected before applying an EWMA chart. The value of the weight factor is usually set between 0.2 and 0.3 or between 0.05 and 0.25, and the multiple of the rational subgroup SD (L) is typically set at 3 to match other control charts [19]. Shehab and Schlegel [20] also adopted Shewhart, EWMA, and CUSUM charts to monitor and classify the cognitive or physical performance of individual participants. Comparing the evaluations of subject matter experts in the field of human cognitive performance, the sensitivity and specificity characteristics of the three control charts were determined for 174 trials involving 10 participants and 23 cognitive performance assessment measures. This study indicated that continuous performance measures (e.g., reaction time) were best examined with EWMA charts with a large weight factor (approximately .90). Shewhart control charts were moderately effective for these data.

Car-following behavior evaluations are directly analogous to SQC evaluations. Car-following performance is subject to inherent human variability. Special cause variability is analogous to risk factors (i.e., lead vehicle braking) that directly affect driver performance (i.e., time headway to the lead vehicle). If only inherent human variability exists, car-following behavior is assumed to be stable for that individual. If special cause variability exists, car-following behavior is assumed to be instable for an individual, and warnings are then provided to rectify the driver's car-following behavior. Individual differences and "monitor in time" are features of control charts; therefore, control charts are well suited to be adopted in FCW systems.

The aims of this study are to evaluate driver car-following behaviors in Taiwan by 2 driver groups with different types of driving anger, and to examine the differences among participants' driving performances and subjective workloads with various FCW systems.

II. METHODS

A. Participants

We recruited 96 participants who scored in the upper (UKDAS $>$ 84) or lower (UKDAS $<$ 63) quartiles on the 21-item UKDAS (Lajunen et al., 1998) and divided them into 2 anger groups (low-anger vs. high-anger groups). Each participant had a valid driver's license for at least 1 year and had to meet normal vision requirements (a minimum of 18/20 or 18/20 vision after correction), pass the Ishihara Color Card Blindness Test, and demonstrate normal hearing. Exclusion criteria included prior experience using a driving simulator or an HUD. Each participant was in two experiments with high- and low-driving workloads. Each participant who completed the experiment received NT$300.

B. Apparatus

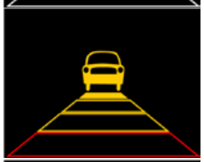
UK driving anger The UKDAS (Lajunen et al., 1998) consists of 21 items describing driving situations that may potentially provoke a driver's anger. The items are divided into three subscales, including impeded progress (9 items), reckless driving (9 items), and direct hostility (3 items). Respondents rated the amount of anger generated by each situation on a 5-point Likert scale (1 = *not at all*; 2 = *a little*; 3 = *some*; 4 = *much*; 5 = *very much*). The Chinese translations are conducted according to the meaning of the UKDAS items to render them appropriate to a Taiwanese sample.

STI driving simulator This study uses the interactive STI® driving simulator developed by Systems Technology Inc., Hawthorne, CA, USA. The simulated vehicle cab, a VOLVO 340 DL, features all standard automotive displays and controls (i.e., steering wheel, brakes, and accelerator) in a vehicle with automatic transmission. The driving scenario is projected onto a 100-in. [(Mocom Power Screen®; screen type: aluminum concave; dimensions (W x H): 200 x 150 cm; curvature: 900 cm; brightness: 20 gains)] screen located 3.1 m in front of the driver with the sound effects of the vehicle broadcasted by two-channel amplifiers.

Head-up display Information related to driving, such as the speed and instructions from the reviewer regarding tasks, are projected on a screen located 3.1 m in front of the driver by the projector. The vertical projection angle is maintained between 6° and 12° below the driver's horizontal line of vision, and the HUD area measures approximately 45 (w) x 30 (h) cm. The display resolution is 1024 x 768 dpi; the presentation font (icon) size is 12 x 12 cm^2 (approximately 2.0°).

Forward collision warning system The FCW system was developed using Visual Basic programming language, and contains three main functions. The first function is to communicate with the STI driving simulator using RS232 serial cables and adapters and to retrieve and decode related driving performances from the STI driving simulator. Second, employing X-bar and EWMA control charts, three FCW systems (i.e., five-stage, X-bar, and X-bar and EWMA control chart systems) are used to aid and alert the drivers in this study. These systems monitor actual time-related driving performances (i.e., time headway to lead vehicle), and set various warning parameters for the different FCW systems. These FCW systems send a warning when the driver follows a lead vehicle too closely. The third function is to display FCWs. The FCW program generates warnings. Auditory warnings are beeps and mixed buzzer sounds that alert the driver in a timely manner and are used to warn drivers of imminent crashes. The multimodal display introduced in this study is a simple combination of auditory and visual displays. Table I shows the time headway intervals of the five warning zones.

TABLE I
TIME HEADWAY INTERVALS OF FIVE WARNING ZONES

Warning zones	***Five-stage mode***	***X-bar control chart***	***EWMA & X-bar control charts***
	1.6 s or greater	Outside upper control limit or in control	EWMA & X-bar: Outside upper control limit or in control
	1.4~1.6 s	Points fall between the centerline and the 1σ limit	EWMA: in control X-bar: Points fall between the centerline and the 1σ limit
	1.2~1.4 s	Points fall between the 1σ limit and the 2σ limit	EWMA: in control X-bar: Points fall between the 1σ limit and the 2σ limit
	1.0~1.2 s	Points fall between the 2σ limit and the 3σ limit	EWMA: in control X-bar: Points fall between the 2σ limit and the 3σ limit
	Below 1.0 s	Outside lower control limit	EWMA: Outside lower control limit or X-bar: Outside lower control limit

C. Tasks

Driving tasks All participants were instructed to proceed to a destination quickly and complete the simulated driving course while following all traffic rules and driving safely.

Car following tasks The participants were instructed to drive as they normally would and to follow the lead vehicle at a safe distance (as specified by the in-car display), although this might involve breaking the speed limit. Fourteen sudden events resulted from lead vehicles braking in various manners (i.e., coasting deceleration, normal braking, and emergency braking) for each road stretch, and the participants were instructed to avoid rear-end collisions. As the participants drove on different road segments with the FCW aids, the FCW system sent warnings to the participants once they began following the lead vehicle too closely. Information related to FCWs is displayed on the head-up display. As the headway time between the participant vehicle and lead vehicle decreased, the distance between the car icons on the display decreased, and the display in the lead vehicle increased in size and changed colors according to different risk levels. When the headway time reached a critical point, the display flashed at 4 Hz. Flashing was used to attract the attention of the driver and to alert the driver of dangerous following distances. Auditory warnings were sent in critical conditions, and the volume was approximately 75 dB.

Divided attention tasks Divided attention (DA) tasks are useful for measuring visual workloads. As shown in Fig. 1, the sign ( ) appears on both sides of the screen. The signs changed randomly every 60 s into red triangles (i.e., or), and remained on display for 5 s. When the change in the two signs' appearances was detected, participants were asked to turn the signal handle in the same direction as the sign on display. The participants were instructed to respond as quickly as possible.

Fig. 1. Divided attention tasks. The signs are randomly changed into red triangles, and remain on display for 5 s. When detecting the change in the two signs appearance, participants are required to turn the indicator in the same direction as the sign on display.

D. Experimental design

Three factors are involved in this mixed-factorial experiment: driving anger (high vs. low; between subjects), driving workload (high vs. low; within-subjects), and the FCW system (five-stage vs. X-bar vs. X-bar and EWMA control charts; between subjects). Variables are assigned to subjects, and are counterbalanced to prevent possible learning or order effects. Each anger group included 48 participants, and was divided into three sub-groups with five-stage, X-bar control chart, or X-bar + EWMA control charts FCW system. Dependent variables based on both objective and subjective measures are described in the following section. To explore the learning effects of car-following behavior with various FCW systems, participants were instructed to separately finish three road stretches with high- and low-driving workloads.

E. Driving scenario descriptions

The environmental driving scenarios were developed using STI Scenario Definition Language (SDL) V.8.0 and were divided into low- and high-load conditions. High- and low-driving load environments differ in the following aspects: number of lanes (high: 2 vs. low: 4), lane width (high: 3.6 vs. low: 4.1 m), number of intersections (high: 50 vs. low: 20), density of roadside buildings (high: 15 buildings/min of driving vs. low: 2 buildings for every 2 min of driving), and density of approaching vehicles (high: 20 approaching vehicles/min of driving vs. low: 10 approaching vehicles/min of driving). All participants were instructed to finish two driving experiments with high- and low-driving workloads separately. Each experiment was approximately 60 km and was divided into three equal parts: the first 20 km (baseline road stretch: driving without the warning system), second 20 km (FCW road stretch: driving with the warning system), and last 20 km (post-learning road stretch: driving without the warning system).

For the entire drive, participants were asked to maintain a speed of 90 km/hr and to follow the lead vehicle. Each 20-km road stretch included 14 sudden events and eight driving anger-induced events, and participants' braking behaviors were elicited by lead vehicle decelerations caused by these sudden events. Lead vehicle decelerations included coasting deceleration, normal braking, emergency braking, stopping ahead of the intersection.

Driving anger-induced events and maneuvers, such as the lead vehicle maintaining a lower speed, are used to induce a participant's driving anger in each road stretch. Four types of driving anger-induced events appeared at random every 1.33 km with no similar events occurring in succession. They are introduced below. (a) The lead vehicle proceeds more slowly in the lane than is reasonable for the traffic flow. (b) A bicyclist is crossing the intersection, forcing the driver to slow to a stop. (c) A vehicle is driving close to a participant's rear bumper, and honks at you repeatedly. (d) A pedestrian walks slowly across the middle of the street, forcing participants to slow to avoid a collision.

Total 14 sudden events appeared in random order with no similar events appearing in succession; these sudden events included approaching vehicle turned left, roadway barrels in the lane, lead vehicle slowed abruptly, crossing vehicle in the intersection, and red light at the intersection. Each kind of sudden events occur three times except red light at the intersection and do not appear in succession on each road stretch. The drivers occurred red light at the intersection twice on each road stretch.

F. Data collection and analysis

We collected both objective and subjective data. The following section describes the dependent measures for assessing the effects of driving anger, driving workloads, and the FCW systems on driving behavior and performance. We analyzed collected experimental data using analysis of variance (ANOVA) by employing SPSS, version 19.0; post hoc analyses were performed using the Tukey method. The level of significance for all analyses was set $\alpha < 0.05$.

G. Procedure

Participants completed the UKDAS and indicated their interest in participating in this study by providing their name and cellphone number. We called the participants with high- (UKDAS > 84) or low- (UKDAS < 63) driving anger to describe the driving simulation experiment and to invite them to participate in this study. Interested subjects were scheduled for individual times in the laboratory.

Before the experiment, participants had to meet the normal requirements for vision and hearing, and were instructed to the operation of the simulator, the experimental procedure, and the tasks. They were given approximately 10 min to practice driving, to familiarize themselves with the simulator controls and to experience lead vehicle decelerations, which would be involved in the experimental trials. The participants were instructed to drive as they normally would and to follow the lead vehicle at a safe distance. All subjects signed a consent form.

The experiment was conducted after the practice session. Participants with the FCW system employing the X-bar or X-bar + EWMA control charts completed 10 min of driving, which entailed following the lead vehicle at a safe distance; this headway time between a participant's vehicle and the lead vehicle was used to compute the mean and SD of the headway time under normal conditions. Each participant completed two different experiment roads (high driving-load road vs. low driving-load road) once, and each experiment was approximately 60 min. The sequences in which the participants finished the two experiments followed counterbalanced rules to avoid order-related effects.

After practicing, the mean and SD of headway time were calculated. All participants were instructed to maintain their speed at the target speed, as directed by the experimenter (90 km/hr), with no lead vehicle, and were instructed to follow the lead vehicle but to avoid a rear-end collision. Participants began a 20-min road stretch with no FCW aids, following the lead vehicle maintaining a safe headway time (baseline road stretch), which was followed by 20 km of driving with the FCW system (road stretch with FCW). Finally, another 20-km drive was conducted without the FCW aids to evaluate the learn effects of safe headway times after the assistance of the FCW system (post-learning road stretch). During each experiment, participants were allowed a 5-min break between the three road stretches to avoid fatigue and order-related effects. After the end of each stretch, NASA-TLX questionnaires were scaled to evaluate participants' subjective workload. Subjective preferences and trust regarding the FCW system were scaled after the end of the road stretch with the FCW. All experiments lasted approximately 60 min.

One week after the first experiment, each participant was asked to participate in a second experiment. In the second experiment, the driving workload experienced by the participant was different from that of the first experiment; the second experiment procedures were similar to those of the first. After the second experiment, we paid each participant NT$300 and thanked them for their participation.

III. RESULTS

A. Braking response time

Braking-response time is defined as the total time recorded from sudden events occurred to the drivers stepped on the brakes. As shown, the results showed that driving workload ($F(1,90) = 162.682$, $p = .000$), FCW system ($F(2,90) = 10.167$, $p = .000$), and driving anger ($F(1,90) = 4.124$, $p = .045$) had a significant effect on braking response time while sudden events occurred, and all interactions were not significant.

The results indicated that the braking response times that participants performed in high workload road condition (1.867 s) were longer than in low workload road condition (1.676 s). The braking response time while sudden events occurred, the braking response times of the drivers with five-stage FCWs (1.833 s) were longer than those in FCWs using X-bar & EWMA control chart (1.718 s) and those in FCWs using X-bar control chart (1.732 s). The difference in braking response time between FCWs using X-bar & EWMA control chart and using X-bar control chart was not significant. In addition, the result showed that the braking response time for low anger drivers (1.738 s) was shorter than for high anger drivers (1.784 s).

B. *Minimum time to collision*

The minimum time to collision with the lead vehicle is recorded through STI driving simulator, and represents the urgency of braking. The results indicated that driving workload (F(1,90) = 28.851, p = .000), FCW system (F(2,90) = 3.756, p = .027), and driving anger (F(1,90) = 19.479, p = .000) had significant effects on minimum time to collision with the lead vehicle. All interactions were not significant.

The minimum times to collision with the lead vehicle that participants performed in monotonous driving road stretches were comparatively long (3.152 s), whereas in complex driving road stretches were decreased significantly (2.927 s). The drivers with FCWs using X-bar & EWMA control chart and with FCWs using X-bar control chart performed longer minimum times to collision with the lead vehicle (X-bar control chart: 3.083 s; X-bar & EWMA control chart: 3.129 s) than the drivers with five-stage FCWs (2.908 s). Furthermore, long minimum times to collision with the lead vehicle while sudden events occurred were performed by low anger drivers (3.193 s), whereas high anger drivers decreased minimum times to collision with the lead vehicle significantly (2.886 s).

C. *Minimum headway with the lead vehicle*

The minimum headway/range is the distance between the driver and the lead vehicle ahead of the driver. The dependent variable represents the urgency of braking. The results showed that FCW system (F(2,90) = 5.655, p = .005), and driving anger (F(1,90) = 5.899, p = .017) had significant effects on minimum headway between the driver and the lead vehicle. All interactions were not significant.

The drivers with FCWs using X-bar & EWMA control chart and with FCWs using X-bar control chart performed longer minimum headway between the driver and the lead vehicle (X-bar control chart: 9.504 m; X-bar & EWMA control chart: 9.674 m) than the drivers with five-stage FCWs (8.436 m). In addition, long minimum headway between the driver and the lead vehicle while sudden events occurred were represented by low anger drivers (9.600 m), whereas high anger drivers decreased minimum headway with the lead vehicle significantly (8.809 m).

D. *Maximum longitudinal deceleration due to the brakes*

The maximum longitudinal deceleration due to the brakes is defined as the maximum braking deceleration recorded in the duration from sudden events occurred to the drivers stepped on the brakes, and represents the critical level of the situation. The results showed that FCW system (F(2,90) = 5.938, p = .004), and driving workload (F(1,90) = 6.103, p = .015) had a significant effect on maximum longitudinal deceleration due to the brakes.

The results indicated that the maximum longitudinal deceleration due to the brakes that participants performed in high workload road condition (-4.375 m/s^2) were larger than in low workload road condition (-3.749 m/s^2). The drivers with five-stage FCWs performed greater maximum longitudinal deceleration due to the brakes (-4.614 m/s^2) than the drivers with FCWs using X-bar control chart (-4.081 m/s^2). The drivers with FCWs using X-bar & EWMA control chart performed moderate maximum braking acceleration (-4.377 m/s^2). The differences of maximum braking acceleration between drivers with FCWs using X-bar & EWMA control chart and with FCWs using X-bar control chart performed were not significant, and similar result was found between drivers with FCWs using X-bar & EWMA control chart and with five-stage FCWs.

The interaction of FCWs× driving workloads (F(2,90) = 3.633, p = .030) indicated that a significant effect on maximum longitudinal deceleration due to the brakes. The comparisons of three FCWs in high and low driving workload conditions were executed. In high driving workload condition, FCW system (F(2,93) = 3.426, p = .037) had a significant effect on maximum longitudinal deceleration due to the brakes. The drivers with five-stage FCWs (-4.581 m/s^2) and with FCWs using X-bar & EWMA control chart (-4.506 m/s^2) performed greater maximum longitudinal decelerations due to the brakes than those the drivers with FCWs using X-bar control chart (-4.1812 m/s^2) performed. The difference in maximum braking acceleration between FCWs using X-bar & EWMA control chart and five-stage FCWs was not significant. In low driving workload condition, FCW system (F(2,93) = 7.665, p = .001) had a significant effect on maximum longitudinal deceleration due to the brakes. The drivers with five-stage FCWs (-4.648 m/s^2) performed greater maximum longitudinal decelerations due to the brakes than those the drivers with FCWs using X-bar control chart (-3.982 m/s^2) and with FCWs using X-bar & EWMA control chart (-4.249 m/s^2) performed. The difference in maximum braking acceleration between FCWs using X-bar & EWMA control chart and FCWs using X-bar control chart was not significant.

E. *Response time of divided attention tasks*

Response time of DA tasks is defined from the time the signs changed into red triangles to the time the indicator is used, and is collected by the STI driving simulator. Response time of DA tasks represents peripheral objects detection ability. The results indicated that driving workload (F(1,90) = 94.128, p = .000), and FCW system (F(2,90) = 3.500, p = .034) had a significant effect on response time of DA tasks. All interactions were not significant.

The DA response time that participants performed in monotonous driving road stretches were comparatively short (1.366 s), whereas in complex driving road stretches were increased significantly (1.562 s). The drivers with five-stage FCWs performed longer DA response time (1.516 s) than the drivers with FCWs using X-bar control chart (1.412 s). The drivers with FCWs using X-bar & EWMA control chart performed moderate DA response time (1.464 s), and had no obvious differences with the drivers with FCWs using X-bar control chart and five-stage FCWs.

IV. Discussion

The FCW is the anti-collision system, which prevents crashes against the lead vehicle due to excessive speed or too short headway. The objective of this study was to investigate the effects of forward collision warnings on driver response and driving performances to imminent collision situations. The experiment data proved that three forward collision warnings provided a substantial benefit, particularly FCWs using X-bar control chart.

The data also identified how a warning impacted the driving performances of driver response process. FCWs aided drivers in avoiding collisions by decrement of braking response time, but it did not enhance the longitudinal deceleration due to the brakes. In the experiment, because compliance with the FCWs caused a faster response of braking, the participants were able to brake more gradually. The greater abrupt deceleration was performed by braking response of driver; the higher risk of collision was triggered. The difference in maximum longitudinal deceleration suggested that a potential indirect benefit of the FCWs was to decrease the risk of multiple car crash due to reduce the maximum longitudinal deceleration.

Moreover, the numerous studies indicate that FCWs are effective for crash reductions, and the majority of previously conducted studies have shown the benefits of FCW systems in maintaining an appropriate headway and reducing the risk of rear-end crashes [11]–[17]. This study provided additional evidence that FCWs were effective for decreasing reaction time for deceleration, preserving the vehicle from collision, maintaining a safe headway.

In general, driver behavioral measures indicated a safety benefit of three FCW. However, the five-stage FCW revealed the worse performances than other systems. The results potentially suggested that individual differences in car-following behaviors were considered for arguing about the benefits of FCWs. Because the common FCW system uses a specific headway as a warning criterion, the warning criterion may be inconsistent with the subjective judgments of drivers. Thus, drivers' performances may decline because of inconsistencies between the FCW criteria and drivers' subjective judgments. Jamson et al. [18] proposed an adaptive FCW system that adjusted the timing of warnings according to each driver's reaction time, and found that benefits of the adaptive FCW system were demonstrated for aggressive drivers. The adaptive FCW systems by using the control chart concept in the study had a highly significant beneficial effect on driver safety, and the study provided additional evidence in line with the similar investigation.

In confirmation of previous findings [3]–[10], the linkages between driving behavior and driving anger were supported in this study. In the present study, it was observed that high anger drivers responded to sudden stop events more leisurely, and preferred shorter TTC and headway with the lead vehicle than low anger drivers. In general, the result suggested that high anger driver had relatively aggressive car following behavior and felt a little annoyance at the FCW, particularly five-stage FCW. The adaptive FCW system was recommended to utilize in the road for the high anger drivers due to avoid the annoyance at the FCW.

In the study, car-following behavior evaluations were directly analogous to SQC evaluations, and this result provided an evidence to express the benefit of the FCW using control charts. Car-following performance is subject to inherent human variability. Special cause variability is analogous to risk factors (i.e., lead vehicle braking) that directly affect driver performance (i.e., time headway with the lead vehicle). The implications of these results are important to the designers of FCW systems. By allowing an individual's preferred time headway with the lead vehicle to affect FCW functionality, the warning criterion is consistent with the subjective judgments of drivers, and is effective for reducing the risk of collision.

As this study has shown, high anger drivers had shorter time to collision and headway to collision with the lead vehicle than low anger drivers in anger-evoked situations. There are several benefits of 3 FCW systems in terms of reduced braking reaction time and increased TTC and time headway, but the important fact is that drivers will more readily accept the FCW using control charts than the five-stage one, particularly the FCW using X-bar control chart. Approximately one-third of participants in NHTSA Field Operational Trial expressed they would have turned FCW off if the FCW system could be closed [21]. To avoid the annoyance from the FCW, the adaptive FCW likes the FCW using X-bar control chart was likely to be used more consistently and had a positive help for reducing risk of collision.

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References

[1] Institute of Transportation, Taiwan. Transportation Research Statistics in 2010. Retrieved October 20, 2012, from http://www.iot.gov.tw/ct.asp?xItem=606377&ctNode=1448&mp=1, 2011.

[2] The Ministry of Interior, Taiwan. Statistical Yearbook of Interior. Retrieved July 20, 2012, from http://www.moi.gov.tw/stat/index.aspx, 2011.

[3] J. L. Deffenbacher, R. S. Lynch, L. B. Filetti, E. R. Dahlen, and E. R. Oetting, "Anger, aggression, risky behavior, and crash-related outcomes in three groups of drivers." *Behaviour Research and Therapy,* vol. 41, pp. 333-349, 2003. http://dx.doi.org/10.1016/S0005-7967(02)00014-1

[4] P. Ellison-Potter, P. Bell, and J. L. Deffenbacher, "The effects of trait driving anger, anonymity, and aggressive stimuli on aggressive driving behavior." *Journal of Applied Social Psychology,* vol. 31, pp. 431-443, 2001. http://dx.doi.org/10.1111/j.1559-1816.2001.tb00204.x

[5] R. Fernandes, J. Hatfield, and R. F. Soames Job, “A systematic investigation of the differential predictors for speeding, drink-driving, driving while fatigued, and not wearing a seat belt, among young drivers.” *Transportation Research Part F,* vol. 13, no. 3, pp. 179-196, 2010. http://dx.doi.org/10.1016/j.trf.2010.04.007
[6] H. Iversen, and T. Rundmo, “Personality, risky driving and accident involvement among Norwegian drivers.” *Personality and Individual Differences,*vol. 33, no. 8, pp. 1251-1263, 2002. http://dx.doi.org/10.1016/S0191-8869(02)00010-7
[7] T. Lajunen, D. Parker, and H. Summala, “Does traffic congestion increase driver aggression?” *Transportation Research Part F,* vol. 2, pp. 225-236, 1999. http://dx.doi.org/10.1016/S1369-8478(00)00003-6
[8] J. Mesken, M. Hagenzieker, T. Rothengatter, and D. Dewaard, “Frequency, determinants, and consequences of different drivers’ emotions: An on-the-road study using self-reports, (observed) behaviour, and physiology.” *Transportation Research Part F,* vol. *10*, no. 6, pp. 458-475, 2007. http://dx.doi.org/10.1016/j.trf.2007.05.001
[9] M. Moore, E. R. Dahlen, “Forgiveness and consideration of future consequences in aggressive driving.” *Accident Analysis & Prevention,* vol. 40, no. 5, pp. 1661-1666, 2008. http://dx.doi.org/10.1016/j.aap.2008.05.007
[10] P. Ulleberg, “Personality subtypes of young drivers. Relationship to risk-taking preferences, accident involvement, and response to a traffic safety campaign.” *Transportation Research Part F,* vol. 4, no. 4, pp. 279-297, 2002. http://dx.doi.org/10.1016/S1369-8478(01)00029-8
[11] T. A. Dingus, D. V. McGehee, N. Manakkal, S. K. Jahns, C. Carney, and J. M. Hankey, “Human factors field evaluation of automotive headway maintenance/collision warning devices.” *Human Factors,* vol. 39, no. 2, pp. 216-229, 1997. http://dx.doi.org/10.1518/001872097778543930
[12] M. Maltz, and D. Shinar, “Imperfect in-vehicle collision avoidance warning systems can aid distracted drivers.” *Transportation Research Part F,* vol. 10, pp. 345–357, 2007. http://dx.doi.org/10.1016/j.trf.2007.01.002
[13] A. Ben-Yaacov, M. Maltz, and D. Shinar, “Effects of an in-vehicle collision avoidance warning system on short- and long-term driving performance.” *Human Factors,* vol. 44, no. 2, pp. 335-342, 2002. http://dx.doi.org/10.1518/0018720024497925
[14] J. D. Lee, M. L. Ries, D. V. McGehee, T. L. Brown, and M. Perel, “Can collision warning systems mitigate distraction due to in-vehicle devices.” *National Highway Traffic Safety Administration*, 2000.
[15] J. D. Lee, D. V. McGehee, T. L. Brown, and M. L. Reyes, “Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator.” *Human Factors,* vol. 44, no. 2, pp. 314-334, 2002. http://dx.doi.org/10.1518/0018720024497844
[16] R. Mohebbi, R. Gray, H. Z. Tan, “Driver Reaction Time to Tactile and Auditory Rear-End Collision Warnings While Talking on a Cell Phone.” *Human Factors,* vol. 51, no. 1, pp. 102-110, 2009. http://dx.doi.org/10.1177/0018720809333517
[17] J. J. Scott, and R. Gray, “Comparison of visual, auditory and tactile warnings for rear-end collision prevention in simulated driving.” *Human Factors*, vol. 50, pp. 264-275, 2008. http://dx.doi.org/10.1518/001872008X250674
[18] A. Jamson, F. Lai, and O. Carsten, “Potential benefits of an adaptive forward collision warning system.” *Transportation Research Part C,* vol. 16, no. 4, pp. 471-484, 2008. http://dx.doi.org/10.1016/j.trc.2007.09.003
[19] D. C. Montgomery, *Introduction to statistical quality control* (5th ed.). New Jersey: John Wiley, 2005.
[20] R. L. Shehab, and R. E. Schlegel, “Applying quality control charts to the analysis of single-subject data sequences.” *Human Factors,* vol. 42, no. 4, pp. 604-616, 2000. http://dx.doi.org/10.1518/001872000779698033
[21] National Highway Traffic Safety Administration, *Automotive collision avoidance system – field operational test report.* (DOT- HS- 809- 900). Washington, DC: US Department of Transportation, 2005.

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