EVALUATION OF MESSAGES ON INFORMATION DISPLAY BOARD (IDB) USING LABORATORY EXPERIMENT

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ABSTRACT

Six Information Display Boards (IDBs) were erected by California Department of Transportation along a segment of Interstate 80 in the San Francisco Bay area to convey traveler information. The IDBs use LED technology, which provides full-color display aiming for better legibility and enhanced recognition. Five categories of messages are proposed to be displayed: travel time messages, transit travel time messages, special messages, up-to-six-lines messages and Graphic Route Information Panels (GRIPs). Varying factors such as with/without symbol, sizes and designs of symbols, and color combinations, were considered for the sign design. A laboratory experiment was conducted to evaluate the understandability of the different designs. Participants viewed signs displayed on a HTML webpage which they had complete control over how long to view each sign. The measurements included comprehension accuracy, viewing time and perceived easiness. Considering the population of native Spanish speakers living along the Interstate 80 corridor is higher than 40%, the effect of native language was evaluated. In total 52 participants took part in the study, to include both young and elderly, male and female, and native English and native Spanish speaking drivers. The results show that symbolic signs are superior to pure-text signs in terms of understandability. Large symbols with simple representation are better understood than small symbols. The viewing time of GRIPs especially dual-link GRIPs is significantly longer than other signs. Consistency on message content, symbol design and color combinations increase the understandability of signs. Participants' education level and language had significant influence on the understanding accuracy.

Keywords: Information Display Board, Understandability, Graphic Route Information Panel (GRIP)

INTRODUCTION

Interstate 80 (I-80) is one of the most congested freeways in the Bay Area. The morning commute along westbound I-80 from Hercules to San Francisco in East Bay and the afternoon reverse traffic from San Francisco to Gilman Street are the region's most notorious locations for traffic congestion (*1*). When incidents happen, unexpected traffic jams cause secondary accidents, making the traffic worse.

To relieve the congestion on this route, California Department of Transportation (Caltrans), in cooperation with other agencies, are implementing an I-80 Smart Corridor Project between the Carquinez Bridge and the Bay Bridge. Purpose of this project is to use intelligent transportation systems to improve travel time reliability and reduce accidents and associated congestion (*2*). One part of the system is to display traveler information messages such as congestion level and expected travel time on the Information Display Boards (IDBs). The IDBs have a form factor that differs from typical Model 500 CMS (changeable message sign). The visible optical area is 157 1/2" x 196 7/8", with resolution of 216 x 270 pixels full matrix. It includes technological features to enable full-color display in order to provide better legibility and enhanced sign recognition. Thus, the messages could be displayed in both text and graphical forms. Five categories of messages including travel time messages, transit travel time messages, special messages, up-to-six-lines messages and Graphical Route Information Panels (GRIPs) are proposed to be displayed on IDBs. The primary purpose of these messages is to convey real-time traveler information to enhance drivers' knowledge of the downstream traffic conditions and alternative routes or transportation modes. Caltrans also plans to display public safety messages such as adverse weather conditions. All these messages are proposed to help drivers make better informed decisions, with the potential to reduce the traveling time and thus reduce the congestion level on the road.

In order to evaluate the effectiveness of traffic signs, researchers have suggested different measurements. From a survey of traffic sign experts in Australia, New Zealand, and the United States, Dewar examined several criteria for traffic sign symbols and the importance of the criteria in the design and evaluation process. Understandability was rated as the most important factor, with conspicuity the second. Reaction time, legibility distance, and glance legibility were rated as equally important (*3*). In one study Janice Mackeit-Stout and Robert Dewar conducted in 1981, glance legibility, legibility distance, comprehension, preference was used to identify the adequacy of signs. Significant positive correlations were found among the first three measures (*4*). Using a driving simulator, Charlton compared multiple measures of sign processing, including attentional conspicuity, search conspicuity, implicit and explicit recognition, dynamic comprehension, static comprehension, and sign priming. It was found that attentional conspicuity, search conspicuity, and static comprehension were the most reliable indicators of a sign's overall performance (*5*). Based on previous studies, it could be concluded that understandability/comprehension is one of the most important for evaluating the performance of traffic signs.

Understandability of a sign is affected by multiple factors. The relationship between sign comprehension and sign features has been studied by Ng & Chan in 2007. Their findings showed that guessability score of traffic signs varied with familiarity, concreteness, simplicity,

meaningfulness, and semantic closeness (*6*). A study by Ben-Bassat & Shinar in 2007 that evaluated the influence of ergonomic principles of familiarity, standardization, and symbol-concept compatibility on traffic sign comprehension showed that comprehension was highly correlated with the compliance with these ergonomic design principles (*7*).

Due to the capability of full-color display of IDBs, the use of symbol would be an important factor to consider. Ells and Dewar conducted two experiments to measure the time required to comprehend the meaning of traffic signs. The results indicated that signs with symbolic messages could be understood more quickly than those with verbal messages (*8*). Chan & Ng pointed out that the influence of a symbols' visual features (color, shape, size) and cognitive features (familiarity, concreteness, complexity, meaningfulness, semantic distance) should be considered for the symbol (*9*).

GRIPs have the potential to display greater detail of traffic information than traditional CMS. Some studies have been conducted regarding the design of GRIPs. A simulator experiment has been conducted in the Netherlands to test and compare the comprehension of regular CMS and GRIPs. It was found that increased message complexity reduced driving speed (*10*). The influence of orientation to processing time has also been studied. The research findings from Munich and the Netherlands both recommended the use of a bottom-to-top display (*10, 11*). Additionally, regarding the use of colors on GRIPs, some guidelines have been developed such as consistency in the use of color codes, avoidance of using colors from extreme ends of the color spectrum next to each other, and familiar color coding (*12*).

The effective communication of sign messages is not only related to the sign features, but also the driver factors. Al-Madani and Al-Janahi studied the relationships between the comprehension of traffic signs and driver factors. The results showed that the age, gender, education, and income played major roles (*13*). Studies conducted by Dewar, Kline, and Swanson also found that drivers in older age understood traffic signs more poorly than younger ones (*14*). However, the effect of drivers' native spoken language has been rarely investigated.

In the present study, we conducted a research using human-factors approaches in order to evaluate the designs for messages on IDBs. We considered design factors such as with/without symbol, symbol designs, and color combination in order to identify a better design for each message. Besides, we aimed to conduct fundamental research for the evaluation of signs on IDBs which has the potential to be generalized on other corridors in California and across the country.

MESSAGES AND ALTERNATIVE DESIGNS

There are five categories of messages proposed to be displayed on IDBs: travel time messages, transit travel time messages, special messages, up-to-six-lines messages, and GRIPs. Exemplar signs are shown in Table 1.

TABLE 1 Five Categories of Messages

Category	Exemplar Signs

Travel time messages	 
Transit travel time messages	  
Special messages	 
Up-to-six-lines messages	 
GRIPs	 

- Travel Time Messages: The purpose of this category of messages is to convey estimated travel time to popular and noticeable destinations, including conjunctive highways and airports;
- Transit Travel Time Messages: This category of messages is trying to convey the information of travel time from certain starting points to various destinations by taking public transportations such as BART and bus (AC Transit and WESTCAT);
- Special Messages: The purpose of this category of messages is to convey information about incidents, roadwork, adverse road conditions as well as the abnormal status of train, BART and bus services.
- Up-to-six-lines message: This category of messages designs both graphical and text messages containing up to six lines with a clear horizontal line to break the message into two virtual phases.
- Graphic Route Information Panel (GRIP): GRIPs include single-link and dual-link based GRIP. A single-link based GRIP presents travel time to four different destinations on the current route. A dual-link based GRIP has two links presenting travel time to different destinations along two different routes. This is a new category of messages, which Caltrans wants to explore the

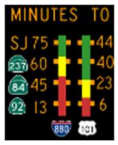
possibility that link-based GRIPs are more informative than text-based designs. The messages use colors to represent the congestion level. The used colors are green (normal operating speed), yellow (slow traffic conditions) and red (stop-and-go conditions). These colors have been proven well interpreted by drivers and more helpful for drivers to make decisions of selecting alternative routes compared with text-based messages, according to a study conducted by Texas Transportation Institute in 2008 (*15*).

Alternative Designs for Each Category of Messages

For each category of messages, alternative designs have been derived based on considered design factors. Design factors include with/without symbol, color combination, various symbol designs, color combinations. Alternative designs of messages are evaluated in order to compare the effects of different design elements and explore a better design for each message. In total, 34 signs for 15 types of messages are included in the lab experiment, as illustrated in Table 2.

TABLE 2 Messages and Alternative Designs

Category	Message	Designs	
		#1 Symbol with text	#2 Text only
Travel time messages	Highways		
	Airports		
Transit travel time messages	BART		
	AC Transit		
	Westcat		
Special messages	Accident ahead		

	Roadwork				
	Slippery when wet				
		#1 Large symbol		**#2 Small symbol**	
	No Bart service				
	Bus delayed				
	Train delayed				
		#1 Yellow horizontal line		**#2 White horizontal line**	
Up-to-six-lines messages	Six lines				
	Four lines				
GRIPs		**Bottom to top**		**Top to bottom**	
		#1 No legend	**#2 With legend**	**#3 No legend**	**#4 With legend**
	Single-link				
	Dual-link	**Routes on top**		**Routes on bottom**	
		#1 Destinations in the middle	**# 2 Destinations on the left**	**#3 Destinations in the middle**	**#4 Destinations on the left**
					

- Travel time messages: In order to compare the IDB designs using both symbols and texts versus the existent designs (e.g., Model 500 CMS) using only texts, the travel time messages are also displayed in pure text format.

- Transit travel time messages: Transit travel time messages are also evaluated with and without symbol. The symbol used in the message sign has the original color combinations from the transit agency, which is familiar to people.
- Special messages: Two design factors are considered for the special messages. One design factor is whether having symbols in the message is easier to understand. For messages of abnormal transit services (i.e., no BART service, delayed bus service, delayed train service), the other design factor is the format of symbols, including shape, size, and color.
- Up-to-six-lines messages: In order to break the messages into two virtual phases, the color of the horizontal line is considered as a design factor for up-to-six-lines messages, which is hypothesized to have different visual effects.
- GRIPs: Five design factors are considered for GRIPs. The first factor is the complexity of the messages, which is presented by the number of links (single-link or dual-link) and the number of destinations (3 or 4 destinations). For single-link GRIPs, two other factors are considered: (1) orientation of approaching destinations (top-bottom or bottom-top), and (2) with and without roadwork/accident legends in conjunction with color-coded congestion levels. For dual-link GRIPs, two other design factors are considered: (1) position of the destinations (on the left side or in the middle of the two links) and (2) position of the route shields (at the top or bottom of the links).

Telegra traffic control software made available by Caltrans was used by researchers to generate Travel Time Messages and up-to-six-lines messages. Other categories of messages are designed based on the considered factors. Adobe Photoshop cc was used to edit the graphical images of message signs. All images were generated as PNG files with a resolution of 3600 * 4500 pixel which matched the aspect ratio of the IDB.

An HTML webpage was developed to display all the sign images. The webpage displayed sign images in a random sequence with one sign each time. The webpage started displaying one image upon click on the button of Start/Next and ended up displaying upon click on the sign image. The time of displaying each sign was recorded by the webpage.

METHOD

The main independent factor of this study was the design factors for each message category. Blocking factors were also considered in this study, which included participants' gender (male and female), age (elderly and non-elderly), and native languages (English and Spanish), which have been suggested to potentially account for comprehension variability of traffic signs (*13*).

Participants

In total 52 participants took part in the study, including 27 native English speakers and 25 native Spanish speakers. The number of non-elderly and elderly drivers, are 28 and 24, respectively. The grouping of non-elderly and elderly is explained further below. The number of male and female drivers are 27 and 25, respectively. There are a minimum of 6 participants in each sub-group. The numbers of participants in each category are listed in Table 3.

TABLE 3 Number of Participants in Each Demographic Group

Language	Gender	Age	Number of participants
Native English speakers	Male	Non-elderly (18-64 years old)	9
		Elderly (65 years old and above)	6
	Female	Non-elderly (18-64 years old)	6
		Elderly (65 years old and above)	6
Native Spanish speakers	Male	Non-elderly (18-64 years old)	6
		Elderly (65 years old and above)	6
	Female	Non-elderly (18-60 years old)	7
		Elderly (61 years old and above)	6

During the process of recruiting elderly female native Spanish speakers, it was found that female native Spanish speakers who live along the I-80 corridor seldom drive themselves after they become 65 years old. They either rely on their family members to drive them around or use other transportation modes (e.g., bus service). Considering this fact, the threshold of elderly female native Spanish speakers was lowered from 65 to 61.

More information about the drivers are given in Table 4. All participants have high school and above education. Years of driving experience and times of driving on I-80 corridor in each month indicate participants' driving experience is evenly distributed and 60% of them travel more than 5 times each month along the I-80 corridor.

TABLE 4 Participants' Demographic Information

Education	Percentage	Driving experience (years)	Percentage	Times of driving on I-80 (per month)	Percentage
Middle school or under	0	Less than 10	3 (6%)	Less than 5	21 (40%)
High school	15 (29%)	10 to 30	15 (29%)	6 to 15	9 (17%)
College graduate	23 (44%)	31 to 50	27 (52%)	16 to 30	14 (27%)
Post graduate	14 (27%)	51 and above	7 (13%)	31 and above	8 (15%)

Procedures

The lab testing was conducted in a quiet conference room at the Richmond Field Station of the University of California at Berkeley. Upon arrival, participants were given a brief introduction of the study including the purpose of the study and testing procedure. After the introduction,

participants were asked to read and sign an informed consent form and then a demographic information form including information about age, gender, education level, times of driving along the I-80 corridor et al. Participants were seated at a table, facing a computer monitor which was 8 feet away. The computer monitor was ASUS PB328Q model with 32 inches WQHD resolution display (Figure 1).

FIGURE 1 Experiment Set-up

Participants viewed signs displayed on an HTML webpage, one sign at a time. Participants had complete control over how long to view each sign. When feeling confident of understanding the meaning of the message, participants used a mouse to click the sign. Then the sign was hidden. The HTML webpage recorded the start and end viewing time for each sign. After that, the experimenters asked questions about the specific sign in order to collect participants' comprehension and recommendation. The questions included:

- What information does the sign provide? Please list some details that you saw.
- Is it easy or difficult for you to understand the sign, on a scale of 1 to 5, 1 is very hard and 5 is very easy?
- (For designs with symbols) Did you see the symbol on the sign? Do you understand the meaning of the symbol? How helpful is the symbol for your understanding of the sign, on a scale of 1 to 5, 1 is not helpful at all and 5 is very helpful?
- What recommendations do you have in order to improve this sign?

Measurements

With the procedure described above, data pertaining to participants' understanding of each design was collected. More specifically, the measurements included:

- Comprehension accuracy: Did a participant understand the message correctly?
- Easiness to understand: Was it easy or difficult to understand each message?
- Viewing time: How much time did it take a participant to process the message?

- Helpfulness of symbols: Did a participant think symbols on the sign helped them to understand the message?
- Recommendations: What design elements caused drivers' confusion and how did each participant suggest to improve?

RESULTS

Understandability of each message category is analyzed, including comprehension accuracy, viewing time, perceived easiness and symbol helpfulness if there is any. The detailed results are tabulated in Table 5. Some participants have misunderstood some specific design elements (i.e., certain wording, symbol, or abbreviations), which contributed to the variance of overall understanding accuracy, viewing time and perceived easiness. After analysis of understandability, comprehension of specific elements and improvement recommendations are summarized. Finally, recommendation of new designs for each problematic sign are proposed.

TABLE 5 Understandability of All Signs

Category	Message	Designs	Accuracy	Viewing time (seconds)		Perceived easiness		Symbol helpfulness	
				Mean	Variance	Mean	Variance	Mean	Variance
Travel time messages	Highways	#1	77.3%	15.64	6.69	3.26	3.92	4.82	0.49
		#2	82.0%	14.22	6.92	3.30	3.44	-	-
	Airports	#1	82.0%	13.79	6.39	3.53	3.38	4.74	0.59
		#2	83.0%	13.22	5.82	3.43	3.07	-	-
Transit travel time messages	BART	#1	91.8%	14.12*	4.88	3.70	2.36	4.65	0.86
		#2	90.5%	18.98*	9.66	3.56	2.63	-	-
	AC Transit	#1	83.3%	17.76	6.79	3.32*	3.27	4.58	0.84
		#2	72.9%	18.11	7.18	2.78*	3.82	-	-
	Westcat	#1	89.1%	14.50	4.89	3.58	2.39	4.40	1.03
		#2	87.8%	14.67	6.18	3.22	2.90	-	-
Special messages	Accident ahead	#1	100.00%	7.06*	2.99	4.51	1.02	4.37	1.13
		#2	100.00%	5.88*	2.61	4.59	0.81	-	-
	Roadwork	#1	100.00%	7.50	2.36	4.64*	0.66	4.79	0.50
		#2	100.00%	7.49	2.76	4.26*	1.08	-	-
	Slippery when wet	#1	100.00%	5.33	1.69	4.72*	0.54	4.93	0.25
		#2	100.00%	5.74	2.50	4.03*	1.74	-	-
	No BART service	#1	100.00%	9.26	3.56	4.36	0.97	4.31	1.28
		#2	97.8%	9.58	3.98	4.31	1.12	4.29	1.28
	Bus delayed	#1	100.00%	8.18*	3.15	4.48	1.01	4.41	1.28
		#2	95.8%	9.89*	4.55	4.22	1.61	4.26	1.03
	Train delayed	#1	91.5%	9.36*	4.17	3.98	2.30	4.39	0.93
		#2	87.8%	11.65*	5.74	3.89	2.15	4.11	1.06

Up-to-six-lines messages	Four lines	#1	82.2%	14.08	4.24	3.07	3.01	4.54	0.69
		#2	65.2%	14.15	6.74	2.55	4.25	4.74	0.62
	Six lines	#1	79.2%	19.42	9.54	3.26*	3.76	4.70	0.69
		#2	87.5%	16.54	5.61	3.74*	3.06	4.69	0.63
GRIPs	Single-link	#1	87.5%	17.84	10.18	3.26	2.68	3.97	1.40
		#2	91.8%	17.05	6.14	3.67	2.59	4.31	1.18
								4.22[a]	1.19
		#3	83.0%	15.88	5.10	3.38	3.33	4.09	1.39
		#4	90.9%	17.30	7.25	3.84	2.23	4.36	1.22
								4.52[a]	0.75
	Dual-link	#1	67.4%	23.59	13.3	2.29	3.76	3.85	1.37
		#2	72.9%	24.07	10.81	2.55	4.03	4.03	1.35
		#3	81.3%	23.29	7.93	2.49	3.18	3.77	1.31
		#4	75.6%	27.71	12.80	2.79	3.47	3.90	1.45

*$p<0.05$

[a]Symbol helpfulness for the accident/roadwork legend

Travel Time Messages

Understandability

For the highway travel time message, 77.3% of the participants understood the design with highway symbols, compared with 82.0% for the design without symbols. Paired t-test was used to analyze the statistical difference of viewing time and perceived easiness between the design with symbol and the design without symbol. No significant difference was found. Most participants perceived that the symbols were helpful, with the average of 4.82 for the highway symbols and 4.74 for the airport symbol.

Comprehension of specific elements

Some specific elements on the sign led to participants' misunderstanding of the message. For the above travel time messages, four design elements caused confusions to the participants:

- Symbol of 580/880: Thirteen participants misunderstood this part of the message as from I-580 to I-880. One example of participant's verbatim was "drives from 580 to 880. But does not tell where the destination is." The difference between this line of information between the design with symbols and the design with pure text is that the "/" on the pure-text design is missing on the with-symbol design. It could be the reason that lowered the understandability of the design with symbols.
- "via": Nine participants commented that this element was confusing. They either misunderstood it as from 92 to 880 or didn't know what it meant. The word "via" was hard to understand for those participants.

- Airplane symbol: In the travel time message to airports, the airplane symbol was on top of the three lines of travel time information. Ten participants misunderstood this sign and thought that it went to one airport only.
- SJC: Sixteen participants didn't understand this line of message. After viewing the sign, they right away asked what SJC meant.

Recommendations

- Show I-580 and I-880 on separate lines, in order to make the sign as simple as possible.
- Avoid using “via”.
- Airports & airplane symbol: put the text of "AIRPORTS" on the top of the message and put the airplane symbol in each line.
- SJC: put SJC only (without “via 880”) or remove this line because San Jose airport is far away. Hence this piece of information is less likely needed for people who travel on the I-80 corridor.

Transit Travel Time Messages:

Understandability

83.3% of participants understood the AC transit travel time message with the AC transit agency logo, compared with 72.9% without the transit logo. Paired t-test was used to analyze the statistical difference of viewing time and perceived easiness. The perceived easiness for the with-symbol design (mean=3.32, STD=3.27) was significantly higher than the perceived easiness of without-symbol design (mean=2.78, STD=3.82).

For the BART travel time message, 91.8% of participants understood the design with the BART logo, compared with 90.5% without BART logo. The viewing time for the with-symbol design (mean=14.12, STD=4.88) was significantly shorter than the viewing time (mean=18.98, STD=9.66) for the without-symbol design.

Comprehension of specific elements

Four design elements on the transit travel time messages caused confusions to the participants:

- The first phase of the messages: Twelve participants didn't understand whether these messages were about public transportation or about driving. One reason for this confusion could be that participants were not familiar with the public transportation agencies. Another reason could be that the message didn't have the clear format or wording to indicate travel time from which station to which station.
- The second phase of the messages: For the second phase of the message, 5 participants mentioned that they were not sure whether the number was time for the bus to arrive at the station or travel time to certain destinations.

- Abbreviation of DN (del Norte): They could not interpret it as del Norte and suggested that it should be spelled out.
- Information lacking: Ten participants commented that these transit travel time messages were lacking information for decision making. Further information such as parking availability in bus or BART stations was needed.

Recommendations

- Add a bus symbol to indicate bus services (AC Transit and WESTCAT).
- Revise wording into “From XX station to XX”.
- Spell out DN as del Norte.
- Remove the horizontal line.
- Further decide upon the needs of putting transit travel time messages on highway signs.

Special Messages:

Understandability

The accuracy for the special messages of ACCIDENT AHEAD, ROADWORK, SLIPPERY was 100% for designs both with symbols and without symbols. It indicates that these designs are fairly simple and easy for everybody to understand. Paired t-test was used to analyze the statistical difference of viewing time and perceived easiness. For the ACCIDENT AHEAD message, viewing time of the with-symbol design (mean=7.06, STD=2.99) was significantly longer than the viewing time of the without-symbol design (mean=5.88, STD=2.61), which could be caused by the pink color of the symbol. For the ROADWORK message (mean=4.64 vs. mean=4.26) and the SLIPPERY special message (mean=4.72 vs. mean=4.03), the perceived easiness of the with symbol design was significantly higher than the perceived easiness of the without-symbol design.

For the special messages about the abnormal status of transit services, the designs with large symbols had higher understanding accuracy compared with the designs with small symbols. The large-symbol designs needed significantly shorter viewing time, for both the DELAYED BUS message (mean=8.18 vs. mean=9.89) and DELAYED CAPITOL CORRIDOR message (mean=9.36 vs. mean=11.65).

Comprehension of specific elements

Four design elements on the special messages caused confusions to the participants:

- The pink color of the accident symbol: Twenty-one participants commented on the pink color of the symbol for the message of "ACCIDENT AHEAD". Exemplar verbatims were "not seen pink color before", "pink means relax". This could be one reason why this design needed longer time to understand.
- The green background color of "No service" or "Service delayed”: Fifteen participants expressed the concern regarding the green background color for the special messages of no

service or delayed service, which was perceived as confusing. Exemplar verbatims were “green means go”, “color green means good rather than a problem”.

- Similar symbols for BART & Capitol Corridor: Sixteen participants commented that the symbol for BART and symbol for Capitol Corridor looked similar.
- No estimated delay time of bus/train: Sixteen participants commented that there was no estimated delay time for the messages of delayed services for bus or train. One exemplar verbatim was “without how long of delay, still don't know what to do”.

Recommendations

- For the ACCIDENT AHEAD message, change the color of the symbol from pink to yellow, which is a standard cautionary color.
- Change the green background of “NO SERVICE” or “DELAYED SERVICE” to other cautionary colors, in order to draw attention.
- For BART service and Capitol Corridor related messages, use their own logo rather than the light-rail symbol
- Add estimated delay time for bus/train if possible.

Up-to-six-lines messages

Understandability

For the four-line message, the accuracy of a white-line design was much lower than a yellow-line one. One reason could be that the viewing sequence of the yellow-line design and the white-line design was unbalanced. For most of the participants the white-line design was viewed before the yellow-line design. Hence the yellow-line design was more likely to be understood because of the learning effect. The unbalanced viewing sequence was caused by the pseudo-random number generator of HTML.

For the six-line message (travel time to DOWNTOWN SF and SAN JOSE), the perceived easiness for the design with a white line (mean=3.74, STD= 3.06) was significantly higher than the design with a yellow line (mean=3.26, STD=3.76).

Comprehension of specific elements

Two design elements on the up-to-six-lines messages caused confusions to the participants:

- MI (miles) and MIN (minutes): Sixteen participants thought both the two numbers were minutes. Hence it made them question why there were two different numbers. Exemplar verbatim was “not sure why there are two-time slots”
- Consistency between the two phases of the messages: On the message of travel time to DOWNTOWN SF, it showed both travel time by driving and by BART, five participants said that they were expecting a similar set of information for travel time to San Jose.

Recommendations

- For the four-line message, spell the MI out and avoid use the abbreviation, or remove MI, or change the layout to distinguish them.
- For the six-line message, put the two phases of the message in the same format, in order to make it as easy to understand as possible.

GRIPs

Understandability

The average viewing time for every design of single-link GRIP was higher than 15 seconds. The comprehension accuracy of designs with legends (91.8% and 90.9%) was higher than the accuracy for designs without legend (87.5% and 83.0%). The viewing time for every design was longer than 15 seconds. ANOVA was used to analyze the difference between viewing time and perceived easiness among the four designs, no significant difference was found.

The accuracy of dual-link GRIP was below 90%, the viewing time was above 23 seconds, the perceived easiness was lower than 3 and the symbol helpfulness was much lower when compared with other message categories. No significant difference was found among the four designs regarding viewing time and perceived easiness.

Comprehension of specific elements

Two design elements on the GRIPs caused difficulties for participants to understand the messages:

- Units of information: Many participants commented that there was too much information shown on one sign. Especially for the dual-link GRIP, 21 users thought it was too complicated and needed time to learn and try to understand it. Exemplar verbatims were “too much information, probably will slow down the traffic” “too much information, I have to study it”.
- The color of GRIP: Fifteen participants didn't understand the meaning of the colors on the GRIP. Misunderstandings of the color included "I don't know what it (the color) means, red looks like a warning", "red is stop, yellow is caution, green is go".

Recommendations

- Only display single-link GRIP with a smaller number of destinations (2 or 3). Give time for the public to learn the format of GRIP; Gradually display more destinations or display dual-link GRIP.
- Educate the public about meanings of the three colors on GRIP.
- Add crash or roadwork legends if applicable.
- Use an arrow to indicate the orientation.
- Either use color coding to show congestion levels or use numbers to show minutes. Not show both at the same time.

Effects of Language, Age, Gender, and Education

The effects of language, age, gender, and education level were analyzed. Understanding accuracy, average viewing time, the average perceived easiness across signs were calculated and analyzed using ANOVA. The analyzed results are shown in Table 6. Understanding accuracy represents the ratio of understood signs out of all signs for each participant.

TABLE 6 Effect of Language, Age, Gender and Education

Factor	**Understanding accuracy**		**Viewing time (seconds)**		**Perceived easiness**	
	Mean	**STD**	**Mean**	**STD**	**Mean**	**STD**
Language						
Native English speakers	90.95%*	13.0%	14.51	4.63	3.56	0.87
Native Spanish speakers	83.40%*	13.0%	14.67	4.47	3.58	0.58
Age						
Non-elderly drivers	89.84%	12.17%	14.58	4.90	3.65	0.75
Elderly drivers	84.34%	14.43%	14.59	4.11	3.48	0.73
Gender						
Female drivers	85.2%	15.9%	15.53	5.16	3.61	0.76
Male drivers	89.2%	10.4%	13.71	3.69	3.53	0.72
Education						
High school	79.7%*	17.6%	16.69	4.69	3.43	0.77
College	87.3%*	10.8%	13.76	4.66	3.49	0.76
Postgraduate	95.8%*	5.2%	13.67	3.48	3.88	0.60

*$p<0.05$

There was significant difference in the understanding accuracy between the native English speakers (Mean=90.95%, STD=13.0%) and the native Spanish speakers (Mean=83.4%, STD=13.0%). There was no significant difference in viewing time and rating of easiness between the native English participants and the native Spanish participants.

Education had a significant effect on understanding accuracy. Post-hoc analysis (Turkey) was used to analyze the difference between each two education levels. It was found that there was a significant difference in understanding accuracy between participants with high school education (Mean=79.7%, STD=17.6%) and participants with post-graduate education (Mean=95.8%, STD=5.2%). There was no significant difference in viewing time or rating of easiness among participants with different education levels.

There was no significant difference regarding understanding accuracy, average viewing time, or average rating of easiness found between non-elderly and elderly participants or between female and male participants.

DISCUSSION

Traffic sign design should be guided by established ergonomics principles to enhance comprehension (*7*). Based on the analysis, we come out with the following guidelines for four aspects of the IDB design, including (i) use of symbols, (ii) consistency, (iii) simplicity; and (iv) provision of sufficient information for decision making.

Use of Symbols

According to the results of understandability for travel time messages, transit travel time messages, and special messages, most designs with both symbol and texts have higher understanding accuracy, require shorter viewing time, and have higher perceived easiness comparing with their pure-text counterparts.

Regarding the size of symbols, large symbols require shorter viewing time when compared with small symbols according to the statistical results of the public transportation-related special messages. For the consideration of alternative designs for the public transportation-related special messages, one intention was to reflect the abnormal status (i.e., NO BART, DELAYED BUS, DELAYED CAPITOL CORRIDOR) on symbols. Therefore, additional elements such as NO SERVICE, DELAYED were added and new symbols were designed. However, those additional elements may have made the symbols too complicated, which took participants longer time to comprehend. Large symbols with simple presentation help drivers to understand traffic sign quicker.

Consistency

For the special messages, many participants commented on the pink color of the ACCIDENT AHEAD symbol, which was unusual and consumed extra time to process. For the public transportation-related special messages, many participants expressed concerns about using a green background color for abnormal public transportation service messages. This reflects the fact that the green color is usually used to indicate good working status rather than abnormal status. Colors such as yellow or amber should be used for warning and to draw special attention, which is actually well-aligned with the CA MUTCD.

A few participants also commented on the consistency problem with the six-line message, which was used to show travel options to downtown San Francisco and San Jose. Although the two phases of the message were independent of each other, participants still expected to see similar patterns of information across the two phases. With consistent patterns across the two phases, it would require less mental workload to process the information on the sign and also make it easier to remember the information after viewing the sign.

Simplicity

For the dual-link GRIPs, almost half of the participants commented that it was way too

complicated to put so much information on one sign. The dual-link GRIP resulted in lower understanding accuracy, in comparison with the six-line message. Some participants explicitly expressed the preference of the six-line message over dual-link GRIP.

One reason is that the format of the six-line message is simpler than the format of dual-link GRIP. Both of the two types of messages have different routes and multiple destinations. However, the dual-link GRIP has 3 or 4 destinations, compared with 2 destinations on the six-line message. Besides the travel time (minutes), it also adds the element of different colors that almost one third of participants don't understand. The above effects add up and make the dual-link messages too hard to understand.

For some Spanish speakers, it was hard to understand the word "via". For example, the airport message, they were more inclined to misunderstand "SJC VIA 880" as going to all three airports (SFO, OAK and SJC) via I-880. For the elderly drivers, although there was no significant difference in their understanding comparing with the non-elderly drivers, many of them conveyed that they would prefer to get the information at one glance. If it is too complicated, they would give up on studying it. Hence, although the IDB is capable of providing more information on one sign, it should display simple messages in order to make it easy to understand for all drivers.

Sufficiency

Transit travel time messages and public transportation-related special messages were designed to be displayed on the IDB, in order to provide information about alternative transportation modes besides of driving. Many participants had the question that why these messages were needed if they were already driving on the highway. Besides, in order to make the decision of taking public transportation rather than driving, other additional extra information such as parking availability, bus or BART arrival time and travel time, how to get from the transit station to their final destinations, would further be required. However, presenting all the above necessary information on one sign would lead to other challenging questions.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Pei Wang and Ching-Yao Chan; data collection: Pei Wang and Tingting Zhang; analysis and interpretation of results: Pei Wang and Tingting Zhang; draft manuscript preparation: Pei Wang and Tingting Zhang, and Ching-Yao Chan. All authors reviewed the results and approved the final version of the manuscript.

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